COURSE IN EXPERIMENTAL PHYSICS

ALEXANDER

FOURTH EDITION

LOWER DIVISION

AN

ELEMENTARY COURSE

IN

EXPERIMENTAL PHYSICS

BY

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PREFACE.

In order to keep the work in Physics at the University of California properly related to that of the secondary schools of the state, it has been found necessary to eliminate many of the more elementary exercises that appeared in the previous editions of this course. The remaining exercises have been revised and rearranged, and, with some additional matter, will comprise the laboratory course in Elementary Physics to be given in 1901–02.

The author wishes to acknowledge his indebtedness to Professor Slate and Mr. F. R. Watson for many valuable suggestions and changes in the text, and to Mr. P. G. Nutting for working out the experimental details of the new exercises.

Arthur C. Alexander.

Berkeley, Cal., May 1, 1901.

PREFACE

TO THE FIRST EDITION.

THIS is not intended to be a complete laboratory manual, or text-book. It simply contains the directions for a series of laboratory exercises in Elementary Physics, representing substantially the first year's work in Experimental Physics at the University of California as given in 1896–97. These directions were originally typewritten and duplicated by means of the mimeograph, a method of preparation that, while allowing the instructor great freedom in modifying and adapting the course to his pupils and the exigencies of the laboratory, also entailed considerable time and labor. As the majority of the exercises will be given during the coming year in their present form, it was deemed best to print the entire course, and to modify it, whenever necessary, by supplementary directions. It is not designed to be a course in Physical Measurement, the quantitative feature being retained from necessity, and not choice. The primary object of the exercises is to illustrate and impress on the mind of the student the elementary principles of Physics. A course of lectures and recitations with assigned reading and problems is intended to accompany and supplement the work in the laboratory.

In arranging the sequence of exercises an attempt has been made to have those subjects taken up first that are more readily adapted to the laboratory facilities of the secondary schools, and can be easily comprehended by the immature student. In this way, and by giving an annual examination for advanced standing in the subject, it is hoped to induce many of the best-equipped preparatory schools to carry their pupils somewhat farther in Physics than is required for admission to the University. The subject of Sound presents peculiar difficulties of presentation to a large class in the laboratory, where only one room is available, and all are not gifted alike with the sense of musical pitch. As a result, many interesting and instructive laboratory exercises on this subject had to be omitted, and only two exercises on Sound have been retained in the course.

The author has made a free use of the work of his predecessors, most of these exercises having been adapted from Whiting's "Exercises in Elementary Physics," the text used in the University of Cali-

fornia in 1894–95 and 1895–96. The general arrangement and method of presentation is also that of Whiting. This book represents only another step in the development of an elementary laboratory course in Physics. Many of the exercises described have barely passed the tentative stage, and there is still much to be done in the way of addition and elimination. It is the intention to further amplify and modify the course, and the author will be glad of suggestions from any one interested.

As it is impracticable to furnish a complete set of apparatus for each exercise to every student, or pair of students, it has been found best to arrange the apparatus for the separate exercises on consecutive tables and to let the students pass from one table to another, as the exercises are completed. A laboratory period of two hours and three-quarters is allowed for the performance of an exercise. A division of the subject matter of each exercise has been made, indicated in the text by an extra space and a dash between the lines. Every student is required to complete the first part in order to be credited with the exercise, and he is required to perform as much of the second part as the laboratory period will permit. The students are also required at the close of each laboratory period to leave duplicate copies of their notes with the instructor for correction.

The author has already mentioned the liberal use he has made of Whiting's "Exercises in Elementary Physics." He desires also to express his great indebtedness to the present members of the Department of Physics for the many ways in which they have helped and encouraged him, and for the hearty interest they have taken in the preparation of these exercises.

ARTHUR C. ALEXANDER.

Berkeley, Cal., May 1, 1897.

LIST OF EXERCISES.

LIGHT.

MAGNETISM.

ELECTRO-MAGNETIC RELATIONS.

CURRENT ELECTRICITY.

ELECTRO-MAGNETIC INDUCTION.

COURSE IN

EXPERIMENTAL PHYSICS

GENERAL DIRECTIONS AND SUGGESTIONS.

THE students will, in general, work in pairs. The members of each pair, while performing the experiments together, must make the necessary calculations and write up their notes independently. Not more than two students will be allowed to work together, except by special permission.

As far as is compatible with neatness and accuracy, observations and calculations should be entered directly into the note-book. An original record is always of greater value than one copied from some scrap of paper, and may often show where a slip had been made when the work would otherwise be rejected as worthless.

Write at the top of each sheet (1) your name, (2) the number of the exercise, (3) the date of performance, and number the sheets under each exercise, so that it may be discovered if any are missing.

Although no one will be restricted to any particular form in writing his notes, it is desirable that the results of observations be tabulated whenever possible; that all fractions be written as decimals; and that all calculations be shown in detail.

All questions must be answered in the note-book, and the

proper deductions made. This course is intended primarily to teach the important principles of physics, and a record of measurements made without any deductions will be of little value.

At the end of each session the duplicate notes made with carbon paper are to be left with the instructor for correction and criticism. If unable to complete the required work in the time allotted, the duplicate notes as far as completed must be left as a record of the work done, and a supplementary paper (marked "supplementary") may be handed in later. Notes taken away and brought back later, without special permission, will not be accepted.

Three recitation periods, covering two hours and three-quarters, are allowed for the performance of each exercise, and, except in special cases, students will be required to remain at least two and a half hours.

No one can think clearly or do accurate work in a noisy room. The large number working together make it imperative that all work quietly and talk only in modulated tones.

Those working at any exercise will be held responsible for the apparatus on the table, and will be expected to leave it in good order and condition when through.

In order to be credited with an exercise the student must complete it as far as the division indicated in the text by a dash between the lines, and he is required to complete as much of the remainder as the laboratory period will allow.

The use of results obtained by others or the copying of their notes will under no circumstances be allowed.

The following system of marks will be used:—

1 will denote excellence and in general will only be given when the entire exercise has been completed.

2 will denote that the work is thoroughly satisfactory.

3 will mean that it is slightly deficient. This grade may be raised to a *2* by correcting the errors indicated.

4 will mean that no credit will be given for the work until it is reperformed in a satisfactory manner.

5 will denote failure.

All unsatisfactory work will be returned to the student for correction.

1. BALANCING COLUMNS.

CAUTION.—Lay aside all gold and silver ornaments while working with mercury.

I. Clamp a U-tube in a vertical position to a burette stand, with the bend of the tube resting on the table. Pour into this tube enough mercury to stand about 5 cm. above the table in each arm. Then pour into the longer arm enough water to stand about 13.6 cm. above the end of the mercury column. Work out all air bubbles with a fine wire, and mop up any water resting on the mercury in the short arm with a bit of blotting-paper tied to the end of the wire. Measure the heights above the table of the ends of the mercury and water columns, measuring as nearly as possible to the center of the meniscus in each case. Are the liquids in the two branches at the same level? If not, why? What differences are there between the shapes of the free ends of the two columns?

Find the length of the mercury column that balances the water column, and also the ratio of the two balancing columns (water column to mercury column).

II. Fill the longer arm of the U-tube nearly full of water, and measure the length of the water column, and also of the mercury column that balances it. Find again the ratio of the balancing columns. Is it the same as in I? Why should this ratio be equal to the specific gravity of mercury?

III. Fill one of two beakers, or jars, with water, and the other with a saline solution. Place a leg of an inverted Y-tube

in each of the liquids. Cautiously draw the liquids up in both legs by suction, and close the stem of the Y air tight. Why is the liquid higher in either branch than in the corresponding open vessel? Measure the height of each column of liquid above the level of the liquid in the open vessel. Is it the same for both liquids, or not? Why?

Does it make any difference if the branches of the Y-tube are not of the same diameter, or are not held vertically?

Calculate the specific gravity of the saline solution.

IV. Fill the two branches of a W-tube, one with water and the other with wood-alcohol. This should be done by pouring the liquids into them alternately, a small quantity at a time. Why is it necessary to observe this precaution in filling?

Make the proper measurements and calculate the specific gravity of the wood-alcohol.

Why is it unnecessary to have the ends of the columns at the same level?

V. Answer the following questions:—

1. To what class of liquids is the method of the U-tube inapplicable? Why?

2. In the case of highly volatile liquids, what advantage has the method of the W-tube over that of the Y-tube?

3. Which of the three do you consider to be the most general method?

VI. Take a U-tube, labeled "for coal-oil only," fill one branch with water and the other with coal-oil.

Should the water or coal-oil be poured in first? and into which arm, the longer or shorter?

Make the proper measurements and calculate the specific gravity of the coal-oil.

VII. With the Y-tube and coal-oil instead of the saline solution, find the specific gravity of the coal-oil.

2. VAPOR PRESSURE AND DALTON'S LAW.

Remember the caution of the last exercise.

I. Take a closed tube, at least 80 cm. long, and wipe it clean and dry with a swab tied to a long and stiff wire. Then fill it with mercury by means of a small funnel. Close the open end with the thumb and invert the tube in a reservoir of mercury. After removing the thumb, does the mercury in the tube fall to the same level as the mercury in the reservoir? If not, why? What is meant by the "barometric pressure"?

Measure the height of the mercury in the tube above that in the reservoir. Is it the same as the height of the barometer? If it is not, explain why.

II. Observe the following directions in filling the tube and removing air bubbles:—

Fill to within a couple of cm. of the open end. Close with the thumb and invert a number of times, gathering all the air bubbles adhering to the sides into one large bubble. Then hold erect and fill completely, pouring the mercury in slowly and working out all air bubbles with a fine wire. Again invert in the reservoir. (The amount of air in the tube can be observed by tilting it until the closed end is about 70 cm. above the table.) To further remove the air, place the thumb tightly over the open end of the tube while in the reservoir, and then raise and carefully invert it a number of times, letting the partial vacuum pass slowly from one end of the tube to the other, and finally, holding it erect with the open end up, take the thumb off and fill completely, as directed above. This operation should be repeated until the air bubble seen when the tube is tilted has been reduced to the smallest possible size. Note the metallic click when the mercury strikes the top of the tube. (Be careful not to let it strike too

hard.) The height of the mercury column ought now to agree, within one cm., with the barometric reading for the day.

III. Having measured the height of the mercury column above the level of the mercury in the reservoir, draw as much gasoline as possible into a medicine dropper, and inserting it into the reservoir under the open end of the tube, introduce a few drops of the gasoline into the tube, taking great care not to introduce any air. Introduce enough so that some of the liquid will remain unevaporated on top of the mercury column. Describe in detail what takes place when the gasoline is introduced. Does the gasoline all evaporate, or does it cease to evaporate after a certain amount has been introduced? Explain why, if you can. When is a vapor said to be saturated?

After waiting 15 or 20 minutes for the gasoline vapor to come to the temperature of the room, measure the height of the mercury column. Why is it less than before the introduction of the gasoline? What do you find to be the pressure of the gasoline vapor, in cm. of mercury, at the temperature of the room? (Record this temperature.)

IV. (*a*) Pour more mercury into the reservoir, leaving enough space for the mercury in the tube when it is taken out. With the tube resting on the bottom of the reservoir, measure again the height of the mercury column, and also the length of the tube occupied by the gasoline vapor.

(*b*) Raise the tube so that its lower end is just below the level of the mercury in the reservoir and after a few minutes repeat the measurements of (*a*).

(*c*) Answer the following questions:—

1. Was the pressure of the gasoline vapor in (*a*) the same as in (*b*)?

2. Was its volume the same?

3. The temperature being kept constant, do you find the

pressure of saturated gasoline vapor to depend on its volume, or not?

V. Remove the gasoline from the mercury by wiping its surface with a piece of clean blotting-paper and then passing it through a pinhole at the point of a paper filter. Pour the mercury into a 150-gm. bottle with a rubber stopper, to a depth of 2 or 3 cm. Be sure that the bottle is clean and dry and free of gasoline vapor. (If there is any gasoline vapor in the bottle, it can be removed by inserting a tube and blowing it out.) Insert the short arm of a U-tube, at least 50 cm. long, through the rubber stopper. See that the stopper fits closely into the mouth of the bottle and press it in as tightly as possible. Invert the bottle, taking care not to entrap any air in the mercury column. Resting the bend in the tube on the table, measure the height of the mercury in the tube above, or below, its level in the bottle. Pour gasoline into the tube so as to stand in an unbroken column 15 or 20 cm. deep, and attach a rubber bulb to the open end of the tube. By pressing the bulb, force a little of the gasoline into the bottle, taking care not to force in any air. What is the effect of introducing the gasoline?

VI. Force in about 15 cm. of the gasoline in the tube so that the gasoline in the bottle is at the same level as the mercury had been before, or a trifle above this level. The volume of the mixture of air and gasoline vapor being approximately the same as the volume of the air before the introduction of the gasoline, how does the pressure within the bottle compare with the pressure when it contained air alone? Did the evaporation cease immediately after the introduction of the gasoline, as in III? If it did not, explain why. (Ask, if you do not know.) What do you find to be the effect of mixing gasoline vapor with air, the volume being kept constant?

Watch the mercury column and see that its height becomes constant before taking the measurements in VII.

The mercury ought to become stationary in 20 or 30 minutes.

VII. Find by appropriate measurements the increase of pressure within the bottle over the pressure before the introduction of the gasoline. What does this increase of pressure represent? How does it compare with the pressure of gasoline vapor when unmixed with air as determined in III?

Observe and record the temperature of the room. Is it the same as when III was performed? How would the difference in temperature, if there is any, affect the pressure of the gasoline vapor?

According to *Dalton's law* the pressure of any vapor, or gas, in a gaseous mixture* is the same as it would be if it occupied the space alone. Do the results obtained in VII and in III tend to confirm the truth of this law?

VIII. Remove the gasoline from the mercury by the method of V. Clean the barometer tube carefully and repeat the experiment of II and III with ether instead of gasoline. What do you find to be the pressure of ether vapor at the temperature of the room in cm. of mercury?

IX. Blow the gasoline vapor out of the bottle, and repeat V–VII with ether instead of gasoline.

* Dalton's law does not apply to a mixture of gases, or vapors, that act on each other chemically, or to a mixture of vapors from liquids that are mutually soluble.

3. VARIATION OF VAPOR PRESSURE WITH TEMPERATURE.

I. Fill a deep hydrometer jar with water at about 55°. When the water has cooled to 50° (not before), set in the jar a closed U-tube with a few cm. of ether, free of air bubbles,* in the closed end, and at least 50 cm. of mercury in the rest of the tube. The mercury before inserting in the water should stand a few cm. lower in the open arm than in the closed, and there should be enough water to completely cover the ether. Describe what takes place when ether is warmed in this way.

Suspend a thermometer in the jar on a level with the ether and read the temperature of the water.† At the same time measure the difference in level between the mercury in the two arms of the U-tube. Do this as accurately as you can by placing a metre rod against the side of the jar and sighting across the top of each mercury column. It will injure the rod to put it into the water. Using this last measurement and the barometric pressure for the day, find the pressure, in cm. of mercury, of the ether vapor within the closed arm of the tube.

II. If necessary, siphon off a small quantity of the water and replace it with enough cold water to lower the temperature about 3 or 4 degrees, not more. Repeat the measurements of the last section.

In this way make a series of observations of the tempera-

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* If there is any air above the ether, ask to have it removed.

† To read a thermometer accurately, the observer's eye should be placed so that the first degree mark below the top of the mercury coincides with its reflection in the mercury. The fraction of a division above this mark should be carefully estimated and recorded in tenths of a degree.

ture and pressure of the ether vapor, cooling it down to the temperature of the room or lower.

III. Plot the results of I and II on co-ordinate paper and draw a curve to show the relation between the pressure and temperature of ether vapor.*

Do you find the pressure of the ether vapor to vary uniformly with the temperature or not?

IV. Take some ether in a small test-tube and immerse it in water at about 30°, adding hot water gradually until the ether begins to boil. A small tack or other sharp-pointed object placed in the ether will facilitate boiling. Record the temperature of the ether when it first begins to bubble as the boiling point.

Find from the plot obtained in III, the temperature of ether vapor when its pressure is equal to the barometric reading for the day. How does this agree with the boiling point of ether just found? What relation may one infer exists between the temperature at which a liquid boils and that at which the pressure of its vapor becomes equal to the atmospheric pressure? Explain.

V. Take a small U-tube, similar to that used in I and II, containing wood-alcohol instead of ether. Place it in a vessel of water, heat the water, and determine the boiling point of the wood-alcohol, using the relation just found.

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* In plotting the results of an experiment the scales used and the origin of co-ordinates should be chosen, if possible, so that the curve obtained will reach diagonally across the paper. In general the points found should not be connected by straight lines, making a jagged curve, but a "smooth curve" should be drawn to fit these points within the limits of the errors of observation.

4. VOLUMENOMETER.

I. Unscrew the iron cap of the volumenometer and by raising or lowering the open tube adjust the level of the mercury in the other tube to some point between the middle and the upper marks. See that the iron cap is empty and replace it, screwing it down air-tight.

Bring the mercury to the middle mark and read the heights of the two mercury columns. Without loss of time, bring the mercury to the highest mark and read again the heights of the two mercury columns. Bring the mercury again to the middle mark, and read the heights of the mercury columns. If their difference is not approximately the same as it was before, it means that there has been leakage of air and your observations should be repeated. If it is approximately the same, average the two results.

Using your measurements and the atmospheric pressure for the day, calculate the pressure of the inclosed air when the mercury is at the middle mark, and also when it is at the upper mark. What is the law connecting the volume of an inclosed gas with its pressure, the temperature remaining constant? Apply this law to your results and calculate the ratio of the volume when the mercury is at the middle mark to the volume when the mercury is at the upper mark. How much greater was the volume in the first case than in the second? (See the figures marked on the apparatus. Density of mercury = 13.6 gm. per c. c.) Knowing the ratio of these volumes and also their difference, calculate the volume of the inclosed air when the mercury is at the middle mark.

II. Repeat the measurements of I, using the middle and lower marks instead of the middle and upper marks. From these measurements calculate again the volume of the inclosed air when the mercury is at the middle mark.

Average the results of I and II.

III. Unscrew the iron cap, place within it a piece of thick glass tubing, and screw it on again. Find, as was done in I and II, the volume of the inclosed air to the middle mark. Do you find the volume to be the same as that found in I and II? Why not? Find the difference in volume. To what is this difference equal?

IV. Find the mass of the glass tubing by weighing, and, having found its volume, calculate its density.

V. Find in the same way the density of a short iron rod.

5. PRESSURE OF GAS AT CONSTANT VOLUME.

I. Set a metre rod in a vertical position alongside the open tube of a simple constant-volume air thermometer with a fixed bulb. Fill the space about and above the bulb with ice-water at about 5° or 10°, and stir continuously. Allow a few minutes for the inclosed air to come to the temperature of the bath, and then raise or lower the open tube so as to bring the mercury in the stem of the bulb to the bottom of the tube through which the stem is thrust. Read on the metre rod the heights of the two mercury columns, and take the temperature of the bath.

II. Draw off some of the water and replace it with warmer water so as to raise the temperature of the bath about 10°.* After waiting a few moments, repeat the operations and measurements of I.

In this way make a series of observations of the pressure

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*Do not try to obtain a rise of exactly 10° in temperature. Better results can be obtained and time saved if the bath is raised a trifle over 10° and then stirred till the inclosed air has had time to come to the same temperature as the surrounding water, whatever that may be.

and temperature of the inclosed air, raising the temperature about 10° at a time,—and carrying it as high as can be conveniently done with boiling water. How did the pressure of the inclosed gas (air) alter as its temperature increased? Was the rate of change uniform?

III. Calculate the average increase in pressure for a rise of one degree in temperature. If no observation was made at 0°, calculate from your results, using the atmospheric pressure for the day, the pressure that the gas would have at 0°, if its volume was kept constant? Find the ratio of the average increase in pressure per degree to the pressure at 0°.

Calling P_0 the pressure at 0°, P_t the pressure at t°, and a the ratio just found, write the equation connecting the pressure and temperature of a gas when the volume is constant.

IV. Plot the results of II, plotting the temperatures as abscissæ and the pressures as ordinates.

Draw the straight line that agrees most nearly with the points located on the plot. Find the rise of this line (*i. e.*, the increase in pressure of the gas) for a change of 100° in temperature, and also, from the plot, the pressure of the gas at 0°. From these calculate the ratio of the increase in pressure per degree to the pressure at 0°. How does this agree with the result found in III? Why should this last be the more reliable of the two results?

V. What would be the pressure of a gas at—273° C., supposing there was no change of state or volume? If the pressure of a gas depends on the motion of its molecules, would the molecules have any motion at—273° C.? Then, as heat is the energy due to molecular motion, according to this reasoning could a gas be cooled below—273° C.?

This temperature is called *absolute zero.* The temperature measured in Centigrade degrees from absolute zero is called the *absolute temperature.*

6. EXPANSION OF GAS UNDER CONSTANT PRESSURE.

I. Fill the space about the closed tube, or bulb, of the air thermometer with ice-cold water. Set the slider at the zero of the vertical scale, and adjust the mercury columns so that the mercury in both tubes is at the level of the lower end of the stuffing box. (The mercury column can be set quite accurately by sighting across the end of the brass tube surrounding the glass.) Read the volume of the inclosed gas (air) and take the temperature of the water bath.

II. Raise the temperature of the bath as in Exercise 5, II, about 10° at a time, and repeat for each temperature the operations and measurements of I. What was the pressure of the inclosed air in each case? Was it the same? Was the expansion of the air uniform?

III. Calculate the average expansion for a rise of one degree in temperature. If no observation was made at 0°, calculate from your results the volume that the gas would have had at 0°. Find the ratio of the average expansion per degree to the volume at 0°,—in other words, the *cubical coefficient of expansion* between 0° and 1°. How does this quantity compare with the ratio of the increase in pressure per degree to the pressure at 0° when the volume is kept constant? (See Exercise 5, III.)

Calling V_0 the volume of a gas at temperature 0°, V_t the volume at $t°$, and a the coefficient just found, write the law of expansion of a gas at constant pressure in the form of an equation. This is called the *law of Charles* or *Gay-Lussac.*

IV. Plot the results of I and II on co-ordinate paper, plotting the temperatures as abscissæ and the volumes as ordinates.

Find from this plot, by the method used in Exercise 5, IV,

the expansion for a change in temperature of 100° and the volume of the gas at 0°. Calculate from these the coefficient of expansion between 0° and 1°. Is the result the same as that obtained in III?

V. Take a series of measurements for descending temperatures, as was done for ascending temperatures in II.

VI. Plot the results of V and find the contraction of each c. c. of the gas, at constant pressure, between 0° and 1°, by the method of IV. Does the result agree with that obtained for the expansion of the gas?

7. SPECIFIC HEAT.—METHOD OF MIXTURE.

DEFINITIONS.—The *thermal capacity* of a body is measured by the amount of heat required to raise its temperature one degree. The *specific heat* of a substance is the ratio of the heat required to raise a unit mass one degree in temperature to the heat required to raise an equal mass of water one degree in temperature. Hence, if the latter is taken as the unit of heat, the specific heat of the substance will be directly equal to the number of units of heat required to raise one gramme one degree in temperature.

I. Weigh out 300 gm. of lead shot and heat it in a double boiler. After the water in the boiler comes to a boil, stir the shot thoroughly with a wooden paddle and take its temperature. Repeat this until the temperature of the shot becomes constant. Have about 75 gm. of ice-water ready. Take successively the temperature of the shot and of the water, stirring each, and pour both into a metal cup. (This should be done quickly so as not to let the shot and water change any in temperature before being mixed.) Stir the mixture and take

its temperature until the latter becomes fairly constant. Record the final temperature of the mixture.

From the results obtained calculate:—

1. The number of units of heat gained by the water, using as the unit of heat the amount of heat required to raise one gramme of water one degree in temperature.*

2. The number of units of heat lost by the shot (in terms of s, the specific heat of lead—an unknown quantity).

Form an equation between these two quantities, assuming that the heat lost to the cup and the room can be neglected, and calculate s, the specific heat of lead.

II. Calculate, as nearly as you can from this result, the mass of water which would have brought the mixture to the temperature of the room.

Repeat I, using this mass of water and the same mass of lead shot (300 gm.), both being at the same temperature as in I. Why should the value of the specific heat thus found be more reliable than that found in I?

Drain the water from the shot, and spread it out on a cloth to dry.

III. Find, in a similar manner, the specific heats of copper and brass, using at first about 100 gm. of each to 75 gm. of ice-water.

IV. Find also the specific heat of coal-oil, using instead of the metal cup a bottle with a cork into which the warm coal-oil and the ice-water can be poured and shaken together, and taking about 1 gm. of coal-oil at 70° to 2.5 gm. of water at 10°. Care should be taken in warming the coal-oil not to ignite it.

*This unit of heat is known by the names *calorie*, *therm*, and *gramme-degree*. Another unit of heat frequently used is the *Calorie*, or *kilogramme-degree*.

8. LATENT HEAT.

I. Weigh out in a metal cup at least 500 gm. of water at about 30°. After recording the exact temperature of the water, take a piece of ice (about 100 gm.) and place it in the cup, wiping it carefully with wet cotton. Stir the mixture thoroughly and take its temperature when the ice disappears.

Having previously weighed the water, the mass of the dry ice used can be found by weighing the mixture and subtracting the mass of the water. The mass of the cup when empty should also be found.

II. Calculate in order the following quantities, using the same unit of heat as in Exercise 7:—

1. The heat lost by the water poured over the ice.
2. The heat lost by the cup. (In calculating this quantity it will be sufficiently accurate to take the specific heat of the metal as 0.09.)
3. The heat required to raise the water from the melted ice from 0° to the temperature of the mixture.
4. The total heat absorbed by the ice in melting.
5. The heat absorbed by each gramme in melting.

The latter quantity is called the *latent heat of fusion* of water.

III. Fill a small copper boiler about two-thirds full of water and insert through the cork stopper a safety-tube with an opening about 2 cm. from its lower end. Connect to the boiler a rubber tube with a trap for collecting the water condensed in the tube and a delivery-tube 4 or 5 cm. long. Bring the water in the boiler to a boil. (If at any time steam issues vigorously from the safety-tube, it means that the water is low and the boiler needs refilling.)

Weigh out about 500 gm. of ice-water in a metal cup, and take its temperature. Empty the water out of the trap and

hold it so that the delivery-tube is well immersed in the ice-water. Stir and observe the temperature as it rises. When the temperature reaches a point as much above the temperature of the room as the original temperature of the ice-water was below, remove the delivery-tube. Stir and take the temperature again carefully. Replace the cup on the balance and find the increase in the mass of the water due to the steam that has been condensed. Empty the water out of the cup and find the mass of the cup itself.

IV. If the temperature of the water was as much above the temperature of the room after the condensation of the steam as it was below before the introduction of the steam, we may safely neglect the effect of the air and surrounding bodies, for the cup will lose to the room, by radiation and conduction, as much heat in the latter part of the experiment as it gains from it in the first part. Using the same unit of heat and the same value for the specific heat of the metal cup as in II, calculate in order the following quantities:—

1. The total amount of heat imparted to the water and the cup.

2. The heat given out by the water from the condensed steam in cooling from 100° to the temperature of the mixture.

3. The total amount of heat given out by the steam or water vapor in changing from the state of a vapor to that of a liquid.

4. The heat given out by each gramme of water vapor in changing from the gaseous to the liquid state.

The latter quantity is called *latent heat of vaporization* of water.

V. Repeat I and II with great care and calculate again the latent heat of fusion of water.

VI. Repeat III and calculate again the latent heat of

vaporization of water. Repeat until concordant results are obtained. Do not reject any of the results unless there is good reason for doing so.

9. SPECIFIC HEAT.—METHOD OF FUSION.

I. Weight three, or more, balls of different metals.

II. Suspend one of the balls in a vessel of boiling water for a few moments. Melt with it a cavity in a block of ice deep enough to hold the ball, and replace it in the boiling water. Let it remain long enough to acquire the temperature of the water. Carefully dry the cavity in the ice with some absorbent cotton. After squeezing the water out and weighing the cotton, transfer the ball quickly to the cavity and cover it closely with the weighed cotton to exclude the air. When the ball has come to the temperature of the ice, soak up with the cotton the water from the melting ice, taking care not to wipe the exterior surface of the ice. Replace the absorbent cotton on the scales and find the mass of the water from the melted ice.

III. Repeat II with each of the other balls.

Calculate the heat given out by each ball in cooling from the temperature of boiling water to that of the melting ice, using 80 for the value of the latent heat of fusion of water. How many units of heat were given out by each ball in cooling one degree? How many units of heat were given out by each gramme in cooling one degree? Was this quantity the same for each ball?

Of the results found, which represent the thermal capacities of the balls, and which the specific heats?

Are the results of this exercise very reliable? What do you consider the chief sources of error?

IV. Repeat I–III with other balls of the same or different metals, and find the specific heat of as many metals as you have time for.

10. MECHANICAL EQUIVALENT OF HEAT.

I. Take two bottles and put in each of them a kilogramme of lead shot. Place these bottles in a mixture of ice and water.

When the shot in one of the bottles has cooled about 3° below the temperature of the room, shake it thoroughly and take its temperature carefully. Then pour it into a tube of pasteboard, or bamboo, about one metre long, and close the end of the tube securely. Raise the end of the tube containing the shot with sufficient velocity to keep the shot from falling, and when it reaches a vertical position, let the shot fall vertically, like a solid mass, through the length of the tube. Repeat this again and again, keeping count of the number of times the shot falls.

PRECAUTIONS, ETC.—The shot should not be raised too suddenly, so as to throw it violently against the side of the tube, nor should the tube be raised or lowered so as to lengthen or shorten the distance fallen through by the shot.

It is well, also, to hold the tube about a foot from each end, so that there is no danger of any heat being imparted to the shot from the hands. The following method of raising the shot and reversing the tube is recommended: Lay the tube on the table, and raise the end containing the shot, while the other end rests on the table. Let the shot fall, and then lower the raised end. Raise the other end, which now contains the shot, and let the shot fall again. Then lower this end, and again raise the end which contains the shot; and so on.

After the shot has fallen through the length of the tube a

hundred times, insert a thermometer through a side opening, and take its temperature again. Why has the temperature of the shot risen above that of the room?

II. Replace the shot in the ice-water to cool, and while the tube is still warm, repeat the operation and measurements of I, using the shot from the other bottle, which should be about 3° below the temperature of the room. (Its temperature can be raised by shaking the bottle, if it is too low.) Repeat the experiment in this way, cooling one bottle of shot while using the other, until concordant results are obtained.

III. Remove the stopper and measure the distance from the end of the tube to the top of the shot. What is the average distance fallen through by the shot in each reversal of the tube? In one hundred reversals? How far would the shot have to fall to raise its temperature one degree? How far would one gramme have to fall to raise its temperature the same amount (one degree)? How much work, in gramme-centimetres, would be required to raise one gramme of shot one degree in temperature? The specific heat of lead is about 0.032. Using this, calculate, in gramme-centimetres, the amount of work necessary to raise one gramme of water one degree in temperature. This last quantity is called the *mechanical equivalent* of the heat unit.

11. MEASUREMENT OF SURFACE TENSION.

General Directions.—Whenever the beaker used in this exercise is emptied, wipe it carefully with a clean cloth and rinse it thoroughly with warm water before filling it again with another liquid. The rectangles used should also be cleaned at the same time.

In reading the balance the eye should be placed so that the pointer, or some point on the lower end of the spring, appears to coincide with its image in the mirror.

I. Fill a beaker, about 7 cm. in diameter, with a solution of soap in water. Replace the pans of a Jolly balance by a wire rectangle 2 cm. wide, hung vertically, and hold the beaker so that the rectangle is immersed to a certain definite depth in the soap solution. See that there is no soap film within the rectangle, and read the balance.

Let the rectangle dip in the soap solution so that a film is formed within it. Raise or lower the beaker so that the rectangle is immersed to the same depth as before and again read the balance. What difference does the presence of the film make in the reading of the balance? To what force is the elongation of the spring due? How does the elongation vary with the force producing it? (Ask, if you do not know.)

Repeat the measurements until concordant results are obtained.

II. Repeat the measurements of I, using rectangles about 4 and 6 cm. wide. How do you find the tension of the film to vary with its width?

III. Find the elongation of the spring produced by a small known weight,—some fraction of a gramme.

Calculate the tension in dynes (980 dynes = weight of one gramme) of each of the three films in I and II. As a film has two surfaces, the width of the surface in apparent tension, neglecting that about the wires, will be equal to twice the width of the rectangle. Using this, calculate in dynes the average tension of the soap solution across each cm. of the surface.

The tension across a unit length of the surface of a liquid is called the *surface tension* of that liquid.

IV. Clean the beaker and rectangle thoroughly, and repeat the measurements of II with water fresh from the faucet.

As a film can not be formed with pure water, take the reading of the balance when the upper side of the rectangle is just

above the surface of the water and again when it breaks away from this surface. The force measured in this way may be regarded as due entirely to surface tension, although this is not strictly true. Repeat until concordant results are obtained.

Calculate the surface tension of the water. How does it agree with that of the soap solution? Which has the greater surface tension, according to your measurements?

V. With the 4 cm. rectangle find the surface tension of wood-alcohol.

VI. Using the same rectangle, find the surface tension of hot water from the heater at the sink, and also of water cooled with ice. Be sure the ice is clean. Does the temperature affect the surface tension appreciably, and how?

12. PRINCIPLE OF MOMENTS.

I. (*a*) Attach a light metal frame to the table so that it can rotate freely about a pivot through its center. Fasten two spring balances to the frame with stout thread, at equal distances on opposite sides of the center, and draw them out so that they are parallel. Read the balances.

Pull one of the balances out so as to double the tension, and adjust them so that they are still parallel. What does the other balance register? When a force tends to produce rotation about a point, what is the effect of doubling this force upon the force opposing the rotation?

(*b*) Move one of the balances to a point at twice the distance from the center as in (*a*) and pull it (parallel to the other balance) so that it registers the same tension as before. Read both balances.

The perpendicular distance from the center of rotation upon

the line of action of a force is called its *lever arm.* When a force tends to produce rotation about a point, what do you find to be the effect of doubling the lever arm upon the force opposing the rotation?

(*c*) The tendency of a force to produce rotation about a point, according to (*a*) and (*b*), is proportional to the product of what two quantities? This product is called the *moment* of the force about the point considered, and is usually taken positive in sign when the force tends to produce rotation in a counter-clockwise direction, and negative when it tends to produce rotation in the opposite direction.

II. (*a*) Take a beam suspended so as not to rub the surface of the table, and connect its middle point to a nail in the table by means of a spring balance. Attach two balances to two screw-eyes, one metre apart, on the opposite side of the beam at unequal distances from its middle point and to corresponding nails in the table. Tighten the cord attached to the first balance. Read all three balances, and measure the distances between their points of attachment to the beam.

(*b*) Loosen, or tighten, the cords a little and read the balances again.

(*c*) Calculate the moment of each of the forces in (*a*) about some point of the beam. Give these moments their proper signs, and find their algebraic sum. Do the same for the forces in (*b*). What is your conclusion as to the value of the sum of their moments when a number of parallel forces in the same plane act on a rigid body so that it is held in equilibrium?

III. Attach three balances at random to the frame used in I, and to nails in the table. Tighten the cords and read the balances. Draw, on a sheet of paper laid underneath the frame, a line parallel to the line of action of each of the forces measured by the balances. Remove the frame and measure carefully the lever arm of each force about the pivot as a

center. Calculate the moments of the forces about the pivot and find their algebraic sum. In addition to finding the sum of the moments about the pivot, find also the sum of the moments of the forces about some point outside the pivot. Do you find the sum of the moments to be approximately the same wherever the center of moments is taken, or not?

IV. Repeat III without the pivot, so that the frame is free to move in any horizontal direction. Make the proper measurements and calculate the sum of the moments of the forces about some point on the table taken at random. Do the same for some other point on the table. Do you find the sum of the moments to be approximately the same wherever the center of moments is taken?

V. If any number of forces in the same plane act upon a rigid body so that it is held in equilibrium, what do you conclude from the results of this exercise must be the algebraic sum of their moments about any point in that plane? The correct answer to this question is called the *principle of moments.*

VI. Definition.—Two equal, parallel forces in opposite directions constitute what is called a *couple.* The perpendicular distance between them is called the *arm* of the couple.

Let a be the arm, and F one of the component forces of a couple. Find the moment of this couple about any point. Is it the same for all points?

13. COMPOSITION OF FORCES.

I. Take a stout beam, over a metre long, and find its weight (in lbs.) by means of a spring balance.

Attach cords of equal length to screw-eyes near the ends of the beam, and suspend it by these cords from two 30-lb. spring

balances hung from nails in the wall, at the same distance apart as the screw-eyes in the beam. Read the balances. What relation exists between the combined readings of the balances and the weight of the beam?

II. Suspend a mass of metal, weighing over 30 lbs., from the middle of the beam and read the balances again. Do the balances read alike? Why? How can you find the weight of the metal from the readings of the balances? What is the weight as thus found?

III. Hang the mass of metal from a point to one side of the middle of the beam and read the balances again. Why do they not read alike now? Does the relation found in I between the total suspended weight and the combined readings of the balances still hold true? Measure the horizontal distances from the cord by which the weight is hung to the cords to which the balances are attached. How do the products formed by multiplying each distance by the reading of the corresponding balance (less one-half the weight of the beam) compare? How might you have anticipated this result from the Principle of Moments? (See Exercise 12, V.)

In general, what is the resultant of two parallel forces in the same direction equal to: what is its direction: and how is its line of action situated with reference to the component forces?

IV. Hang two 30-lb. spring balances from two nails above the blackboard, at least one metre apart, and connect the balances by a cord somewhat over a metre long. From the middle point of this cord suspend the mass of metal used in II and III. Draw on the blackboard lines parallel to the two parts of the cord and lay off on these lines, from their intersection, lengths proportional to the tension in each part of the cord as registered by the proper balance. Construct a parallelogram with these lines as sides and draw the vertical diagonal. Measure the length of this diagonal in lbs., using

the same scale as was used for the sides of the parallelogram. How does this diagonal compare in direction and length with the downward force (weight) of the mass suspended from the cord? What is the value of the weight as found by this method?

V. Hang the mass of metal to one side of the middle of the cord, and construct another similar *parallelogram of forces.* Is the relation between the diagonal and the weight of the suspended mass the same as in IV? What is the value of the weight as found from this parallelogram?

VI. Hang the mass of metal by a single cord from one of the nails. Attach a spring balance to the cord, near the bottom of the blackboard, and pull it horizontally one foot from the vertical. Note the reading of the balance, and measure the vertical distance from the nail to the "line of action" of the horizontal force.

By what two forces was the cord acted upon, and in what direction was their resultant? Which one of these two forces was measured directly? Find the value in lbs. of the other force. (As the two forces are at right angles, this may be done either graphically by constructing a *triangle of forces*, or by calculation from similar triangles.)

VII. Repeat VI, drawing the cord two feet to one side instead of one foot, and find again the value of the weight.

VIII. With the arrangement of VI and VII attach another spring balance to the same point on the cord, and pull one of the balances out parallel to the blackboard and the other at right angles to it, so that they both register 10 lbs. Measure the horizontal distance that the weight is pulled out and the vertical distance from the nail to the plane of the balances. From these measurements and the readings of the balances, find the value of the weight in lbs.

14. ACTION OF GRAVITY.

NOTE.—The pendulum used in this exercise is a long, flat rod suspended at one end by a hinge so that it can swing freely in only one plane.

I. Fasten a strip of white paper to the lower end of a pendulum like the one described, and over it a strip of impression paper with its dark surface next to the white paper. Suspend a hard metal ball by a thread passing over a nail or hook just above the pendulum. The ball when lowered and at rest should hang so as just to touch (not rest against) the lower part of the pendulum. This can be accomplished, either by turning the block supporting the pendulum, or, if that is immovable, by hanging the ball from a bent nail and slipping the thread along this nail. Raise the ball to a definite mark near the top of the pendulum. Pass the thread over two other nails (one on the same level as the first and the other below), and fasten the thread to a screw-eye in the pendulum, so as to draw it to one side of the vertical. The friction of the thread against the nails ought to be sufficient to hold the pendulum out. See that the ball hangs opposite the proper mark. Wait till it comes to rest, and then burn the thread between the two upper nails, so that the ball falls at the same instant that the pendulum is set free and strikes the latter when it reaches the middle of its swing. The ball should strike the impression paper so as to make a mark on the white paper.

Repeat this until two or three marks are obtained in fairly close agreement (that is, within 1 cm., or less, of each other). Measure the height through which the ball falls while the pendulum moves from its extreme to its mid-position. Find the time it takes the pendulum to move this distance, by counting and timing 100 complete vibrations.

Having found the distance fallen through during the time of a half-swing of the pendulum, calculate the average velocity during this time; and from this, the final velocity. (If a body starts from rest and its velocity increases at a uniform rate, the final velocity will be equal to twice the average velocity.)

II. Repeat I with another pendulum of different length, and find, as in I, the average velocity and the final velocity acquired during the time of a half-swing of this pendulum.

III. From the numerical results of I and II deduce answers to the following questions:—

1. Is the distance fallen through proportional to the first or to some higher power of the time? What is the power in question?

2. Calculate the distance that the ball would have fallen through in one second starting from rest, using the results of I and II and averaging the two values found.

3. Is the velocity acquired proportional to the first or to some higher power of the time?

4. Calculate the velocity that would have been acquired in one second, using the results of I and of II and averaging the values found. This quantity (the *acceleration* due to the weight) is usually represented by the letter "g."

IV. With a suitably graduated spring balance find the weight in dynes of a mass of 200 grammes.

Multiply the mass in grammes by the value of "g" found in III. How does the product compare with the weight in dynes as just found?

Given the mass and acceleration (change of velocity in unit time), how in general can the force acting on a body be found?

V. Repeat I with a ball of different mass. Was the velocity acquired in a half-swing of the pendulum the same as in I?

VI. Repeat I with a ball of about the same size, but of different material. Neglecting the effect of the air, was the

velocity found to be dependent in any way on the substance of the falling body?

15. THE PENDULUM. I.

I. (*a*) Suspend a metal ball by a thread from a hook near the ceiling. Measure the length from the point of support to the center of the ball. Lay a rod, or some other "straight-edge," under the ball and at right angles to the length of the table, to mark the position of rest. Pull the ball out parallel to the length of the table, about 5 cm. from the vertical, and let it go. Find the period,—that is, the time that elapses after it passes the mid-position until it passes it again in the *same* direction,—by counting and timing 100 such complete oscillations. Begin to count "one, two," etc., with the second transit, and note the time of 50 complete oscillations as a check.

(*b*) Pull the ball out 10 cm. from the vertical and determine the period as in (*a*).

(*c*) Pull the ball out 30 cm. from the vertical and determine the period as in (*a*).

(*d*) Were the periods determined in (*b*) and in (*c*) the same as in (*a*)? What was the ratio between the amplitude (one-half the distance swung through) and the length of the pendulum in each case? When the amplitude of a pendulum is less than one-tenth of its length, do you find it to have any appreciable effect on the period?

II. Replace the metal ball by one of wood of the same size. Lengthen the thread, if necessary, to make the length the same as in I. Find the period for an amplitude of 10 or 20 cm. How does it compare with the period found in I with the metal ball? Does the period of a pendulum depend in any way on the mass of the bob when the effect of the air is the same?

III. (*a*) Hang the metal ball by a thread from a stand so that the length of the pendulum thus formed is one-fourth of that in I and II. Determine the period as in I.

(*b*) Shorten the pendulum so that its length is one-ninth of that in I and II and determine its period again.

(*c*) By a comparison of the results of I, III (*a*), and III (*b*), find the law connecting the period of a pendulum with its length, assuming that the period varies as some integral root or power of the length.

IV. Replace the wooden ball used in II by an iron ball, and shorten the thread, if necessary, so that the ball will just swing over the surface of a flat, disc-shaped coil carrying an electric current.*

Find the period of the pendulum, with and without the coil underneath. What was the effect of the coil on the period? In what direction was the magnetic force exerted by the coil on the ball? Would this force have the same effect on the period of the pendulum as a change in the force due to gravity? If so, would the effect be the same as that produced by increasing or by decreasing the force due to gravity?

What do you conclude, from this experiment, would be the effect of increasing or decreasing the force of gravity, upon the period of a pendulum?

16. THE PENDULUM. II.

This exercise is to be performed with a pendulum constructed so that it can be made to vibrate in a plane at any given angle with the vertical.

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*Such a coil will produce a fairly uniform magnetic field perpendicular to its surface. The strength of the field may be increased by placing a piece of sheet iron under the coils.

I. (a) Find the period of the pendulum, to a hundredth of a second when set, so that it vibrates in a vertical plane.

(b) Find the period when the plane of vibration makes an angle of 60°.35 with the vertical.

(c) Find the period when the plane of vibration makes an angle of 75°.5 with the vertical.

(d) What is the vertical force acting on the pendulum bob? What is the vertical force acting on unit mass of the bob? Suppose this vertical force acting on unit mass to be resolved into two components, one perpendicular to the plane of vibration of the pendulum, and the other in the direction of its length when at rest. If a pendulum is constrained to vibrate in a particular plane, as in this case, would a force perpendicular to its plane of vibration affect its period or not? Why?

What is the ratio between the force per unit mass in the direction of the length of the pendulum in (a) to that in (b); in (a) to that in (c)?* (Express these ratios as reciprocals.) What is the ratio of the period in (a) to that in (b); in (a) to that in (c)? (Calculate these ratios in decimals.) By com-

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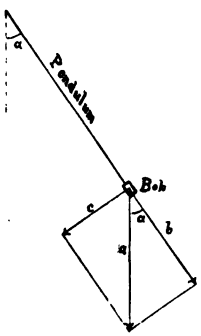

*To find the component of the vertical force on the pendulum in the direction of its length, let a parallelogram of forces be constructed, as in the figure, a being the vertical force on the bob, c the force perpendicular to the plane of vibration of the pendulum, and b that in the direction of its length. As c is perpendicular to b, the parallelogram is rectangular, and by trigonometry we have $b = a \text{ cosine } \alpha$. (In trigonometry, the cosine of any angle of a right triangle is defined as the ratio of the side adjacent to that angle to the hypothenuse, thus in the figure

$$\frac{b}{a} = \cos.\alpha, \text{ or } b = a\cos.\alpha.)$$

In making your calculations, take cos. 60°.35=0.49 and cos. 75°.5=0.25.

paring these results find the law connecting the period of a pendulum with the force on unit mass, or the acceleration, in the direction of its length when at rest, assuming that the period varies as some integral root, or power, of the acceleration. Does it vary directly or inversely?

II. In III of Exercise 15 the period, P, of a pendulum was found to vary according to a certain law with the length of the pendulum, l, and in this exercise to vary according to another law with the force on unit mass, or the acceleration, in the direction of the length of the pendulum. If the pendulum vibrates in a vertical plane under the action of gravity, the latter will be equal to g. Assuming l and g to be the only variables, write an equation giving P in terms of l and g and an unknown constant K.

Substitute the length and period found in Exercise 15, I, for l and P and 980 cm. per sec. per sec. for g, and calculate the value of the constant K. Is the value of this constant thus found a multiple of the quantity π? If so, substitute this multiple of π for K, and write out the final equation for the period of a pendulum.

III. (*a*) If the pendulum swings in a horizontal plane, what will its period be? Set the pendulum in this position and test the truth of your answer.

While in this horizontal position attach to the pendulum bob a long thread stretched parallel to the wall with a light spring at its end, the spring terminating in a straight wire passing through a small hole with a set-screw for fastening it. Hook a small spring balance to this wire and stretch it out with a tension of 2 oz. as measured by the balance. What will be the force acting on the pendulum in the direction of its length?

Set the pendulum vibrating through a very small arc and determine its period.

(*b*) Alter the tension of the spring so that it is 6 oz. as measured by the balance and determine the period of the pendulum again for a very small arc.

How does the force acting on the pendulum in the direction of its length in (*a*) compare with that in (*b*)? As the mass of the bob is the same in both cases, how does the force on unit mass in (*a*) compare with that in (*b*)? What is the ratio of the period of the pendulum in (*a*) to its period in (*b*)? With these results test the law found in I (*d*). Do they tend to confirm it?

17. RESONANCE TUBE.

Description of Apparatus.—The resonance tube to be used consists of a long vertical glass tube connected at its lower end by a rubber tube and siphon with a jar of water, so that when the jar is raised and lowered, the water flows in and out of the tube. The siphon can be started by setting the jar on the floor and pouring water into the tube until it flows into the jar.

I. Hold a vibrating A-fork over the tube, raise the jar, and mark with a rubber band the level of the water when the air in the tube vibrates in unison with the fork and causes a marked increase (a swelling out) in the intensity of the sound.

Lower the jar, and as the water falls, readjust the rubber band to the level of the water when the sound swells out again. Let the water rise and fall past this point a number of times and determine the level when the air in the tube vibrates in unison with the fork, as accurately as you can.

As the air has no freedom of motion in a vertical direction at the surface of the water, the plane where the column of air may be cut off without prejudice to its rate of vibration must be one of minimum vibration, *i. e.*, a *nodal plane*.

Find all the prominent nodal planes you can. Measure the distances between them and between the highest one and the open end of the tube. Is the latter the same as the distance between two consecutive nodal planes? How are these distances related to the wave-length in air of the particular note sounded?

II. Repeat I with a C-fork, and also with a large G- or D-fork.

Find the ratio of the distance between the nodes when the A-fork was used to that when the C-fork was used. This gives the ratio between the wave-lengths. How is this ratio related to the ratio between the vibration frequencies of the two notes? The latter ratio measures the *musical interval* between the notes.

Calculate, from your results, the musical intervals between one of these forks and each of the other two.

III. The velocity of sound in air is given by the formula, $V = 331\sqrt{1+.004t}$ metres per second, t being the temperature of the air in centigrade degrees. Using the velocity of sound given by this formula, calculate the number of vibrations per second of each of the three forks used.

IV. Find the length of the column of air that will vibrate in unison with a tuning-fork when it is held over various hydrometer jars. Measure the diameters of these jars. Is the position of the first nodal plane in a resonance tube affected by the diameter of the tube? What does this last experiment seem to show?

V. With the resonance tube and one of the larger forks, try to find, if you can, the nodal planes belonging to the overtones produced. How are these situated?

18. VELOCITY OF SOUND IN METALS AND GASES.

I. Clamp a long brass rod at its middle point to the table. Take a long glass tube corked at one end and containing fine cork dust and set its open end opposite one end of the rod. A cardboard disc should be attached to this end of the rod, and it should be placed as close as possible to the open end of the tube. Set the rod in vibration longitudinally by stroking it slowly with a cloth wet with turpentine or wood-alcohol. Describe the behavior of the cork dust in the tube. How may the wave-length in the air of the note sounded be determined from the piles of cork dust? In what manner does the brass rod vibrate and how may the wave-length in brass of the note sounded be determined.

Calculate the ratio of the wave-length in brass to the wave-length in air of the same note. How is this ratio related to the relative velocity of sound in brass and air? Using the velocity of sound in air given in Exercise 17, III, calculate the velocity of sound in brass.

II. Repeat I with a glass rod, or tube, and find the velocity of sound in glass.

III. Take a closed glass tube containing air and cork dust, grasp it firmly at its middle point, and stroke it longitudinally. Describe and explain the behavior of the cork dust. Measure as in I, the wave-length in air of the note sounded. Measure also the length of the tube and find the wave-length of the same note in glass. Calculate from these results and the known velocity of sound in air, the velocity of sound in glass. How does your result compare with that obtained in II?

IV. Repeat I with an iron rod.

19. LAWS OF A VIBRATING STRING.

I. (*a*) Attach two German silver wires (about No. 25 and No. 20 B. & S. gauge) to a sonometer and stretch the lighter wire over the sounding-board with a weight of about 4 lbs. Move the sliding bridge until the note given out by the wire when plucked is in unison with a certain tuning-fork. (The note of the fork can be made more audible by holding the end of its handle on the table.) Measure the length of the vibrating part of the wire.

(*b*) Move the sliding bridge so that the note given out by the wire is in unison with the note an octave below that of the tuning-fork, and again measure the vibrating part of the wire.

(*c*) What is the relation between the vibration frequency of two notes separated by an interval of an octave? What, by comparing the results of (*a*) and (*b*), do you find to be the law connecting the length of a vibrating wire (or string) with its vibration frequency?

II. With additional weights increase the tension of the wire to four times its tension in I, and adjust the sliding bridge, if necessary, so that the note given out is in unison with that of the tuning fork. How does the length of the vibrating part of the wire compare in this case with its length in I (*b*)? What do you conclude to be the law connecting the vibration frequency of a stretched wire (or string) with its tension?

III. (*a*) Repeat the experiment of I with the heavier wire and by comparison with the result of I (*a*) find the ratio between the lengths of the two wires when their vibration frequencies are equal. From this find the ratio between the vibration frequencies of the two wires when their lengths are made equal? (See law found in I.)

(*b*) Take two pieces of equal length, one of each kind of

wire, and find the ratio of their masses by weighing on a Jolly balance.

Assuming (the length and tension being constant) that the vibration frequency of a stretched wire (or string) is directly or inversely proportional to some integral root or power of its mass, what do you find this root or power to be?

IV. Repeat I–III, as far as time will permit, with another tuning-fork.

20. PHOTOMETRY.

I. Light a set of four simple gas jets and a single separate jet of the same form, and regulate the flow of gas so that the jets are all of the same height and brightness. Set a diffusion photometer,—two rectangular blocks of paraffine separated by a sheet of tin-foil,—so that the two blocks of paraffine are equally illuminated by the diffused light of the room. Place the single jet at a distance of 50 cm. on one side of the photometer, so as to illuminate one block of the paraffine, and the set of four jets on the other side at such a distance that the two blocks of paraffine will be equally illuminated. Measure the distance from the photometer to the four jets.

How does the illumination of the paraffine due to the single jet compare with that due to the four jets? How does the intensity of the illumination due to a single jet at 50 cm. compare with that due to a *single* jet at the distance of the four jets? The intensity of the illumination is proportional to an integral power of the distance; what, from your results, do you conclude the power in question to be? Is it direct or inverse?

II. Place the four jets at 50 cm. from the photometer and the single jet on the opposite side at such a distance that the

blocks of paraffine are again equally illuminated. Are the conclusions drawn from the results of I corroborated, or not, by the results thus obtained?

III. Light a candle and place it at a certain distance from the photometer. Light a coal-oil lamp and place it on the opposite side of the photometer, so that the candle and lamp illuminate the blocks of paraffine equally. (The height of the lamp wick should not be altered during the course of this experiment.) How can you find the ratio between the illuminating power of the candle and that of the lamp? What is this ratio as derived from your measurements? Repeat the latter until you are sure of your result.

Weigh the lamp and the candle. Let them burn for 30 minutes or so. Reweigh and find the mass of the coal-oil and of the paraffine* consumed. For one gramme of matter consumed by the candle, how many grammes were consumed by the lamp? Calculate the relative illuminating power of coal-oil and paraffine for equal masses (or weights) consumed, assuming that the illuminating power varies directly as the amount of matter consumed.

IV. Alter the height of the lamp flame and repeat III. Calculate again, from the result obtained, the relative illuminating power of coal-oil and paraffine for equal masses consumed. How does the value found compare with that found in III? Is the assumption made above, that the illuminating power varies directly as the amount of matter consumed, corroborated by the results of III and IV, or not?

V. Remeasure the "candle-power" of the lamp in IV by means of a Rumford shadow photometer instead of the diffusion photometer. (Ask for apparatus and necessary directions.)

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*The word "paraffine" is used in this and the next paragraph for the substance of the candle, whatever it may be.

21. REFRACTION OF LIGHT.

I. Take a rectangular cell, having one side of plate glass and containing a mirror revolving on a vertical axis, and fill it about half full of water. Set this cell so that the axis on which the mirror revolves is over the center of a large circle drawn on the table. Adjust the cell so that its glass side is perpendicular to a radius of the circle drawn parallel to the end of the table. This may be done by stretching a white string along this radius, and moving the cell until the image of the string in the plate glass coincides in direction with the string itself. (A piece of blackened tin held back of the plate glass will help in locating the image of the string.)

Move your eye along the edge of the table until you see the image of the string in the mirror above the water. With another white string locate the direction of this image, and stick a pin in line with it on the circle drawn on the table. In the same way look for the image of the string seen through the water and mark with another pin on the circle the direction of this image.

Measure the perpendicular distance from each of these pins to the radius represented by the first string.

Answer the following questions:—

1. Does the light from the first string undergo any change in direction on entering the cell?

2. Will it, therefore, strike the mirror at the same angle within the liquid as without, *i. e.*, above the liquid?

3. Will it be reflected at the same angle within as without the liquid?

4. Will the reflected light, passing through the liquid, have the same direction after leaving the liquid as that which does not pass through the liquid? What do you find by experiment?

The ratio of either side of a right triangle to the hypothe-

nuse measures a function of the angle opposite the side considered, called in trigonometry the "sine" of the angle. Remembering that the first string is perpendicular to the surface of the water at which the light is refracted, how are the sines of the angles of incidence and refraction related to the distance measured above?

The ratio of the sine of the angle of incidence to that of refraction when the light is incident in air, or, more properly, in a vacuum, is called the *index of refraction* of the substance. (If the light is incident in the substance and refracted in air, the index of refraction, on the contrary, is equal to the ratio of the sine of the angle of refraction to that of the angle of incidence.) Calculate from your results the index of refraction of water.

II. Repeat I with the mirror at a slightly different angle and calculate again the index of refraction.

III. Rotate the mirror a little more and repeat I, calculating again the index of refraction.

Do you find the index of refraction to vary with the angle of incidence, or not?

IV. Take a cubical block of glass and lay it on a sheet of brown paper. Mark on the paper the position of two of its opposite edges, and continue the lines with a ruler held against the faces of the cube. Stick a pin in the table about 30 cm. from the cube, and as far to one side as it can be placed without becoming invisible when looked at diagonally through the opposite faces of the cube. Looking at this pin through the cube, place three pins in line with it, one on the same side close to the cube, and two on the side of the observer. Remove the cube and draw lines on the paper to show the direction of the light from the first pin before entering the glass, after passing through the glass, and within the glass. How did the direction of the light before entering the glass cube compare with its direction after passing through the cube?

Draw a line perpendicular to the face of the cube through the point where the light entered, make the proper measurements, and calculate the index of refraction of the glass.

22. REFRACTION AND DISPERSION.

I. Set a mirror in a small rectangular cell, somewhat similar to that used in Exercise 21, and fill it about half full of water. Place the cell with its glass side perpendicular to the line formed by a linear source of light (an electric lamp with "horseshoe" filament) and a narrow slit and at a distance of 100 cm. from the scale of a metre rod set at right angles to the line of the light and slit. Move your eye along the metre rod until the image of the light in the mirror above the water becomes plainly visible and read the scale. Look in the same way for the image of the light in the mirror as seen through the water. Is this image similar in appearance to that seen above the water? Describe and explain the difference. Can you locate its direction, as was done for the image seen above the water?

Locate the direction of the extreme red of the spectrum seen through the water. As the distance of the scale from the cell is one metre (100 cm.), the respective readings of the scale in metres will be equal to the tangents of the angles of incidence and refraction. (See definition of tangent, Exercise 27, foot-note.) Using a table of natural sines and tangents, find the sines corresponding to these tangents, and calculate the index of refraction of water for red light.

Find in the same way the index of refraction for blue light, using the extreme blue of the spectrum; and also for yellow light.

II. Repeat I with a saline solution instead of water. What effect do you find salt in solution to have upon the index of refraction of water?

The angle between the rays of red and blue light after refraction is called the *dispersion* for red and blue light. Do you find the dispersion for pure water to be the same as for water containing salt in solution?

23. IMAGES IN A SPHERICAL MIRROR.

I. Place a concave spherical mirror so as to form as clear an image as possible of the window-sash on a screen, and measure the distance from the mirror to the screen.

Repeat, using some distant object, as the tops of the trees across the road, instead of the window-sash, and measure again the distance from the mirror to the screen. Was this distance greater or less than when the window-sash was focused on the screen? The *principal focus* is the point through which all parallel rays are reflected. Its distance from the mirror is called the *principal focal length* of the mirror. Which of the measurements above may be taken as the principal focal length of the mirror?

II. Place an upright rod at a distance in front of the mirror equal to twice its principal focal length. Adjust the position of the rod by the "method of parallax," so that some definite point on it will coincide in position with its image in the mirror. Do this by adjusting the rod first so as to coincide with its own image*, and then sliding a piece of paper up or down the rod until it meets its image. This will give the required point on the rod. (Do not confound the image formed by the front, plane surface of the glass with that formed by the spherical mirror on the back.) What measurement will now give the radius of curvature of the mirror? Why?

* This can be done by changing the position of the observer's eye and adjusting and readjusting the position of the rod until it will always coincide in direction with its own image from every point of view.

How does this compare with the principal focal length?

III. (*a*) Place the screen at as great a distance from the mirror as the table will allow, and place two gas jets so that their images formed on the screen will be as distinct as possible. To obtain images beyond the center of curvature of the mirror, where did the gas jets have to be placed, between the mirror and the principal focus, between the principal focus and the center of curvature, or beyond the center of curvature?

(*b*) Measure the distance from the mirror to the gas jets and the distance from the mirror to the screen; also the distance between the gas jets and the distance between their images. How does the ratio between the first two distances compare with the ratio between the last two? Find the ratio between the distance of the object and that of its image from the center of curvature of the mirror instead of from its surface. How does this ratio compare with the other two?

(*c*) Reduce to decimals the reciprocals of (1) the distance from the mirror to the gas jets; (2) the distance from the mirror to their images; (3) the principal focal length; (4) the radius of curvature. Of these four reciprocals find two whose sum is equal to a third, and also equal to a simple multiple of the fourth.

IV. Interchange the positions of the gas jets and the screen. (In the new positions they will, of necessity, have to be placed on opposite sides of a line normal to the mirror.) Adjust the screen so as to obtain as definite images as possible, and repeat the measurements of III (*b*). Does the proportion found in III (*b*) still hold true? Does the relation between the reciprocals in III (*c*) still hold true? When the gas jets are beyond the center of curvature, are the images formed between the mirror and the principal focus, between the principal focus and the center of curvature, or beyond the center of curvature?

V. Place a vertical rod between the mirror and its principal

focus, within 8 or 10 cm. of the mirror, and locate its image by means of another rod, using the method of parallax. Measure the distance from the mirror to the object and its image respectively. In order that the relation between the reciprocals found in III (*c*) shall still hold true, what change in sign is necessary?

VI. Suppose an object at an infinite distance from the mirror; where would its image be found, and how would it change in position as the object approached the mirror, supposing the object to approach until it touched the surface of the mirror? State whether the image would be real, or virtual; erect, or inverted; larger than the object, or smaller.

24. CONVEX LENSES.

I. (*a*) With a convex lens form an image of the window-sash on a screen and measure the distance from the lens to the screen.

(*b*) With the same lens form an image of some distant object on the screen, and measure again the distance from the lens to the screen. Is this distance the same as in (*a*)? Which of these distances may be taken as the principal focal length of the lens?

II. Light two gas jets and place them at a distance from the lens equal to twice its principal focal length, and place the screen so as to form as distinct images of the jets as possible. Measure the distances respectively from the lens to the screen, and from the lens to the gas jets. How do these distances compare? Measure the distances between the gas jets and between their images. How do these distances compare?

III. Set the gas jets at a distance from the lens equal to

about five times its principal focal length, and place the screen so as to form as distinct images as possible of the jets.

Measure the distances: (1) From the lens to the screen; (2) from the lens to the gas jets; (3) between the gas jets; (4) between their images. Find a relation existing between these quantities and express it in the form of a proportion?

Reduce to decimals the reciprocal (1) of the principal focal length; (2) of the distance of either gas jet from the lens; (3) of its image from the lens. The sum of what two of these reciprocals is approximately equal to the third?

IV. Interchange the position of the gas jets and the screen and adjust the lens, if necessary, so as to make the images as distinct as possible. Repeat the measurements of III.

Form a proportion, if you can, similar to that formed in III, and find, if you can, a similar equation connecting certain reciprocals.

V. Set an upright rod between the lens and the principal focus. On which side of the lens is the image of the rod? Is the image real, or virtual; erect, or inverted? Locate this image by means of another upright rod, by the method of parallax already used in Exercise 23, II. In order that the relation between the reciprocals previously found should still hold true, what change in sign is necessary?

VI. Answer the following questions as applied to a convex or converging lens:—

1. Where should an object be placed in order that its image may be real? In order that its image may be virtual?

2. When will the image be erect, and when inverted?

3. Where should the object be placed in order to form an enlarged image? In order to form a diminished image?

4. Where should the object be placed in order to use a converging lens as a magnifying glass?

25. CONCAVE LENSES.

I. Locate with an upright rod the image formed by a concave lens of some vertical part of the window-sash, using the method of parallax. (The rod used in locating the image should be looked at *over*, not *through*, the lens.) Measure the distance from the lens to the image.

Locate in the same way, the image of some vertical object in the distance, as the corner of a house, or a telegraph pole, and find the principal focal length of the lens.

II. (*a*) Place the vertical rod at a distance from the lens equal to about twice its principal focal length, and locate its image by means of another vertical rod. Measure the distance from the lens to the image.

(*b*) Repeat with the stationary rod at the principal focus.

(*c*) Repeat with the stationary rod between the principal focus and the lens.

Reduce to decimals the reciprocal (I) of the distance from the lens to the image in either (*a*), (*b*), or (*c*); (2) of the corresponding distance from the lens to the object; (3) of the principal focal length. Which one of these distances should be made negative in order that the sum of the first two reciprocals should be equal to the third?

III. Set two vertical rods attached to the same support at a suitable distance from the lens (to be determined by the student), and locate their images by means of two other separate rods.

Measure (1) the distance of the fixed pair of rods from the lens, (2) the distance of their images from the lens, (3) the distance between the rods, and (4) the distance between their images. Do you find the proportion found in Exercise 24, III and IV, for a convex lens to hold true for a concave lens?

IV. Answer the following questions:—

1. Can a real image be formed by a concave lens?

2. Can a concave lens be used as a magnifying glass?

3. Suppose an object at an infinite distance from a concave lens; where would its image be located, and how would it change in position as the object approached the lens, supposing the object to approach until it touched the lens?

4. Can there be, when a single lens or mirror is used, such a thing as a real and erect image, or a virtual and inverted image?

V. Copy the blank table on the opposite page into your note-books and fill it out from the results of Exercises 23–25:—

		Concave Mirror.	Convex Lens.	Concave Lens.
$D = \infty$	Location of Image	....	....	....
	Real or virtual	....	....	....
	Magnified or diminished......	....	....	....
$\infty > D > 2f$	Location of Image	....	....	....
	Real or virtual	....	....	....
	Magnified or diminished......	....	....	....
$D = 2f$	Location of Image	....	....	....
	Real or virtual................	....	....	....
	Magnified or diminished......	....	....	....
$2f > D > f$	Location of Image	....	....	....
	Real or virtual................	....	....	....
	Magnified or diminished......	....	....	....
$f > D > 0$	Location of Image	....	....	....
	Real or virtual................	....	....	....
	Magnified or diminished......	....	....	....

D = Distance of object from mirror.

f = Principal focal length.

26. DRAWING SPECTRA.

General Directions.—Place a spectroscope so that none of the diffused light of the room will enter its slit, and set a Bunsen flame directly in front of the slit.

To obtain the incandescent vapor of a salt: take a piece of asbestos attached to a wire, dip it into a solution of the salt, and then hold it in the flame. (It is essential that a separate piece of asbestos be used for each salt solution.) Instead of being held in the hand, the wire may be stuck into a cork attached to the spectroscope. If the salt is very volatile, hold the asbestos in the lower edge of the flame; but if refractory, hold it in the hottest part of the flame. Hold the asbestos so that the colored part of the flame is opposite the slit, but do not hold the asbestos itself opposite the slit. In general, the narrower the slit the more distinct the spectrum; but for potassium and thick blue glass the slit will have to be widened.

I. Hold a piece of asbestos saturated with sodium chloride in the flame. Narrow the slit and adjust the focus of the telescope so as to obtain as sharp an image of the slit as possible. Then by moving the scale in or out bring it (the scale) also to a sharp focus. Set the scale so that the yellow band forming the spectrum of sodium will coincide with the division marked 5 (or 50).

Make a copy in your note-book of the spectroscope scale, and draw on it long lines corresponding in position to the band or bands in the spectrum of the salt. Indicate the color of these, and also note the general color of the flame.

II. Draw, as in I, the spectra of salts of potassium, calcium, strontium, lithium, barium, and boron (boracic acid). State in each case the general color of the flame. A trace of sodium is apt to be present in the flame, but its spectrum can be easily distinguished from that of the salt under examination.

III. Draw the spectrum of a luminous flame, and also of the same flame seen through plates of red, green, yellow, and blue glass. Is the light transmitted by any of these plates monochromatic, or not?

27. LAWS OF MAGNETIC ACTION.

PROPOSITION.—If a compass-needle is deflected by a horizontal force acting in an east and west direction, the magnitude of the force will be proportional to the tangent* of the angle of deflection. (Ask for the proof of this proposition.)

I. Place two pocket compasses side by side. Do the like poles attract or repel each other? Do the unlike?

II. Lay a compass on a large sheet of brown paper, draw a circle around it, and mark on the paper the center of the circle, *i. e.*, the position of the center of the compass. Draw a line east and west through this point and mark off on this line points in both directions at distances of 10, 15, 20, 30, and 40 cm., respectively from the center of the compass. Remove all magnetic substances from the neighborhood, replace the compass, and adjust it so that its needle reads zero degrees. (The compass should be tapped very lightly as the needle comes to rest, with the finger or with a rubber pencil-tip.)

Hold a long magnetized steel strip in a vertical position with its lower end on the table at 10 cm. either east or west of the compass, and read the deflection of the compass-needle. (Tap the compass as before, and read both ends of the needle, averaging the readings.) Repeat with the end of the long magnet at 10 cm. on the other side and average the two

* The "tangent" is a function of either acute angle of a right triangle measured by the ratio of the side opposite the angle to that adjacent.

deflections of the compass-needle. To what function of the angle of deflection is the force exerted by the lower pole of the long magnet proportional, assuming that the needle is comparatively short? (See proposition above.)

III. Repeat the last part of II with the end of the long magnet at 15, 20, 30, and 40 cm., respectively, from the center of the compass. Calculate from your results (using a table of natural tangents) the ratio of the horizontal force due to the lower pole of the magnet at 10 cm. to that at 20 cm.; at 15 cm. to that at 30 cm.; at 20 cm. to that at 40 cm.; etc. Does the force vary directly, or inversely, with the distance? Assuming that it varies (directly or inversely) as some integral power of the distance, what do you find to be the power in question?

IV. Take a comparatively short magnet and lay it on the table on a line drawn east and west through the center of a compass-needle, at such a distance as to deflect the needle about 40°. Read the deflection and measure the distance from the center of the magnet to that of the compass-needle. Place the magnet at double this distance, and read the deflection again. Do you find the horizontal force to vary with the distance in this case according to the law found in III, or not? Was the needle in II and III acted on in a horizontal direction by both poles of the magnet, or practically by one alone? Was it in IV?

When a magnet is comparatively short, how do you find the force exerted by it at any point to vary with the distance of the point from the center of the magnet, assuming that it varies as some exact integral power of this distance?

V. A *unit magnetic pole* is a magnetic pole of such strength that it will exert a force of one dyne on a similar pole at the distance of one cm.

The *pole strength* of a magnetic pole is defined as the force exerted by it on a unit magnetic pole at the distance of one cm.

What is the force between two magnetic poles at the distance d apart, the strength of the poles being m_1 and m_2 respectively?

28. MAGNETIC FIELDS.

I. Take a magnet 16.5 cm. long, and locate approximately the mean distance of either pole from the end, by the following method:—

Lay the magnet on a sheet of paper, and trace its outline with a pencil. Place a compass on the paper so that the compass box is about one cm. from the magnet. Commencing near the end of the magnet, move the compass, one or two cm. at a time, parallel to the magnet, drawing, for each position of the compass, lines to indicate the direction of its needle. Remove the magnet, draw a line through the position of its axis, and extend the above lines until they intersect this line. Find a medium point and measure its distance from the end of the magnet.

II. Lay the magnet used in I lengthwise on a large sheet of brown paper. Draw the outline of the magnet with a pencil, and sprinkle iron. filings on the paper around it. Trace the lines in which the iron filings set themselves when the paper is tapped.

Brush the iron filings off the magnet, and return them to the sprinkler, taking care not to scatter and waste them. (In removing iron filings from a magnet, brush them towards the center, and not towards the ends.)

Replace the magnet, and place a small compass at different points of the tracing. How does the direction of the compass-needle at any point coincide with that of the lines of iron filings?

III. Take a sheet of cardboard and place it with its sides

parallel to the edges of the table. To the most northerly or southerly corner of the cardboard fasten a small compass with wax*, and, after removing all magnetic substances from the neighborhood, draw a pencil line to correspond with the magnetic meridian through the compass. On this line place a short magnet with its north pole directed toward the south, and adjust the distance between it and the compass so that the compass-needle is in neutral equilibrium (*i. e.*, will point indifferently in any direction). Fasten the magnet in this position to the cardboard with wax. The compass-needle will not be affected now by the earth's magnetic field, while the sides of the cardboard are parallel to the edges of the table.

IV. Take the drawing made in II. Mark the position of the poles of the magnet, and draw a circle, about 2 or 3 cm. in diameter, around each. Divide these circles into 12 or more equal parts, and through each division draw a line, following the directions in which the iron filings set themselves, as far as these directions can be determined.

Replace the magnet on the paper, and place the compass-needle, protected as in III from the influence of the earth's magnetic field, at the end of one of these lines. Extend this line an inch or so in the direction indicated by the needle. Prolong all the lines through the divisions of the circle in this way, an inch or so at a time, as far as the limits of the paper will allow.

V. Take a point on one of these lines about 9 or 10 cm. from one of the poles of the magnet, and 12 or 15 cm. from the other pole. Suppose a north or south magnetic pole to be placed at this point. Draw lines in the directions that this pole would be urged by each pole of the magnet, and lay off

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*Attach the wax to the edge of the compass, and *do not put it underneath.*

on these lines distances proportional to the forces in these directions due to the poles taken separately. (See law found in Exercise 27, III.) Construct on these lines a parallelogram of forces, and find the direction of the resultant force due to both poles of the magnet. How does the direction of this resultant compare with that of the magnetic line of force at point considered?

If it were possible to produce an isolated north magnetic pole and place it in a magnetic field, how would the path along which it would move be related to the magnetic lines of force? Deduce from this a definition of a *magnetic line of force*. How is the strength of the magnetic field due to the magnet indicated by the lines of force at any point in the preceding diagram?

The sheet of brown paper used in II, IV, and V is to be signed and handed in with the other notes. Each student, however, should make in his note-book a reduced copy of the diagram before handing it in.

VI. Lay two short magnets on a sheet of white paper with impression paper and another sheet of white paper underneath (or they may be laid directly on a page of the note-book). Lay them parallel, side by side, about 1.5 or 2 cm. apart, with their unlike poles opposite. Sprinkle iron filings about them, and trace the lines along which the filings set themselves.

VII. Repeat VI with the magnets placed so that their like poles are opposite.

VIII. Hold a single magnet vertically with its lower pole resting on the paper. Sprinkle iron filings about it, and trace the lines of force due to a single magnetic pole.

IX. Take another large sheet of brown paper, and lay a magnet on it in an east and west direction. With a compass-needle plot, as directed below, the resultant field due to the earth and the magnet, and indicate any neutral points that may be found.

In tracing a line of force, place the compass near the magnet, and make two marks at the ends of the needle, to show its position; then remove the compass, and mark the middle point. Replace the compass so that the south (or north) end of the needle is where the north (or south) end was before; mark the position of the other end of the needle, and find the middle point again. Continue this until the limits of the paper are reached, and draw a curved line connecting the middle points found.

29. INTENSITY OF EARTH'S MAGNETIC FIELD. I.

Caution.—Keep the magnet used in this exercise away from other magnets or magnetic bodies.

I. (*a*) Place a magnet east or west of a compass-needle, as in Exercise 27, IV, at such a distance as to deflect the needle through an angle of 45°. Measure the length of the magnet and the distance of its nearer end from the center of the compass.

(*b*) Reverse the magnet and repeat the measurements of (*a*).

(*c*) Repeat (*a*) and (*b*) with the magnet on the other side of the compass-needle.

II. (*a*) Suspend a carriage for the magnet by two fine parallel wires of equal length, adjusted so that they are east and west of each other. Place a brass rod of about the same size as the magnet in the carriage and carefully draw a line parallel to the rod on a piece of paper placed underneath it. Remove the brass rod and place the magnet in the carriage. Does the magnet lie, as the rod did, east and west, or not? Explain why. Mark on the paper the position of the magnet.

(*b*) Reverse the magnet and mark its position again.

(*c*) Measure the distance between the two wires of the bifilar suspension, and mark their position carefully on the

paper in the three cases above. Find, by measurement from the drawing, the average distance that the lower end of either wire is pulled out from the vertical when the magnet is hung in its carriage.

What forces cause the magnet to be deflected? What is the direction of these forces, and where do they act on the magnet, assuming that the poles of the magnet are at its extremities? Measure on the paper the arm of the couple (see Exercise 12, VI) formed by these forces.

Measure the length of the bifilar suspension and also find the weight of the magnet and carriage. Change the weight from grammes into dynes.

Record all your measurements and preserve the paper diagram for reference, if necessary.

III. Repeat I and II with another magnet of different pole-strength.

30. INTENSITY OF EARTH'S MAGNETIC FIELD. II.

I. In Exercise 29, I, how did the horizontal force at the center of the compass due to the magnet compare in each case with that due to the earth's magnetic field?

Calculate the average force on a unit magnetic pole at the center of the compass due to the nearer pole of the magnet, calling the pole-strength of the magnet P (see Exercise 27, V) and assuming that its poles are situated at its extremities. Do the same for the farther pole of the magnet. How did these forces compare in direction? Find their resultant. How does this resultant compare with the horizontal force (usually denoted by the letter "H") on a unit magnetic pole due to the earth's field? (See question above.)

Form an equation from these results and find from it the numerical value of the quotient H/P.

II. Assuming that the weight in Exercise 29, II, was evenly divided between the two wires of the bifilar suspension, calculate the horizontal force on the lower end of each wire tending to pull it back into a vertical position. Do this by means of a triangle of forces as in Exercise 13, VI, using the length of the wire and the deflection from the vertical, as measured in Exercise 29. In what direction did these forces act, and what was the arm of the couple (see Exercise 12, VI) formed by them? Calculate the moment of the couple formed by these forces.

What two forces tended to deflect the magnet? To what was each of these forces equal in terms of H and P? Calculate the moment of the couple formed by these forces.

What relation exists between the moments of the two couples just calculated? Express this relationship in the form of an equation, and calculate the numerical value of the product $H \times P$.

III. Combine the results found in I and II so as to eliminate the unknown quantity P and find the value of H in dynes.

IV. Repeat I, II, III, using the results of Exercise 29, III.

31. COMPARISON OF MAGNETIC FIELDS.

I. Suspend a magnet in a horizontal position by a long thread (a torsionless thread, if possible), and protect it from air currents by hanging it in a box. When the suspended magnet has been brought to rest, set it vibrating about a vertical axis by bringing an open knife blade near it, and determine its period of vibration within a few hundredths of a

second.* Observe the same caution as in Exercise 29, and also keep all movable magnetic bodies away from the vibrating magnet.

II. Mark in some way the position of one end of the magnet, remove it, and place a compass with a short needle at this point. Place a long magnet at right angles to a line drawn east and west through the thread with its center on this line and its south pole towards the south. Move this magnet parallel to itself until the earth's horizontal field at the center of the compass is as nearly neutralized as possible. Then turn the magnet through 180°, *i. e.*, end for end. Will the intensity of the horizontal magnetic field at the compass-needle now be greater or less than the earth's horizontal field, H? How much greater or less?

Remove the compass, replace the suspended magnet, and determine its period of vibration again as in I. Calculate the ratio of the periods in the two cases. How does this compare with the intensity of the horizontal magnetic fields in the two cases?

Assuming that the period of a vibrating magnet varies as some integral root, or power, of the intensity of the magnetic field parallel to the magnet, what do your results indicate this root, or power, to be? Is it direct or inverse?

III. Suspend your magnet at various designated places in

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*Find the period by the following method: First, find the period to one-tenth of a second by timing about twenty vibrations. Then place your eye in line with the mid-position of the magnet and note carefully the time when the end of the magnet passes this position in a certain direction, east or west. After waiting some minutes longer, time another such transit, and after another like interval a third, and so on. Between each observation there will be an exact number of complete vibrations of the magnet, which may be found by dividing the interval of time by the period found above and taking the nearest whole number. Dividing the interval of time again by this whole number, the period may be found, if the interval of time is long enough, to a hundredth of a second.

the room, determining its period of vibration at each place, and also at a place where H is known. From your results and the law just found, calculate the value of H at each of the places where the magnet was vibrated.

32. ELECTRO-MAGNETIC RELATIONS.

I. Connect the plates of a Daniell cell by a flexible wire cord. Stretch a portion of this cord out straight and hold it near a compass-needle placed on the edge of a wooden block. The electric current is supposed to flow through the external circuit from the copper plate of the cell to the zinc plate. In what direction is the north pole of the compass-needle deflected, or is it deflected at all, when the current and the needle are in the following relative positions:—

1. Current flowing north, needle below?
2. Current flowing north, needle above?
3. Current flowing north, needle east or west?
4. Current flowing south, needle below?
5. Current flowing south, needle above?
6. Current flowing south, needle east or west?
7. Current flowing upward, needle north?
8. Current flowing upward, needle south?
9. Current flowing downward, needle north?
10. Current flowing downward, needle south?
11. Current flowing east or west, needle above or below?
12. Current flowing east or west, needle north or south?

II. Answer the following questions:—

1. How is the direction in which the compass-needle is deflected affected by reversing the direction of the current?

2. How is it affected when its position is changed from one side of the current to the other?

3. Is the force exerted by an electric current on a magnetic pole parallel to the direction of the current or not? What do the results of I, 1 and 2, indicate?

4. What is the direction of this force, with reference to the plane containing the current and the magnetic pole, as indicated by the results of I, 3 and 6?

5. If the needle was not deflected in I, 11, explain why.

6. Suppose the current is represented in position and direction by the fingers of the right hand and the palm to be turned towards the compass-needle, which pole was deflected in the direction indicated by the thumb in I, 1; in I, 2; in I, 3, etc.?

III. Connect the plates of the Daniell cell to a rectangular coil suspended with its terminals in mercury cups so as to turn freely about a vertical axis. Set the coil with its plane north and south. Follow the path of the electric current from the copper plate of the cell through the coil to the zinc plate, and find in what part of the coil the current flows in a northerly direction, in what in a southerly direction, in what part upward, and in what part downward.

Take a magnet and hold its north pole in the following positions relative to the current, observing in each case the direction in which the wire carrying the current, tends to move:—

1. Current flowing north, north pole below.
2. Current flowing north, north pole above.
3. Current flowing south, north pole below.
4. Current flowing south, north pole above.
5. Current flowing upward, north pole north.
6. Current flowing upward, north pole south.
7. Current flowing downward, north pole north.
8. Current flowing downward, north pole south.

How does the force exerted by a magnetic pole upon an electric current compare in direction with that exerted by the

current upon the pole? (Compare the results of I and III.)

IV. Take a suitably mounted annular coil, and connect it to the storage battery terminals. Place a piece of paper on a plane surface perpendicular to the coil through its center and make a pencil tracing of the magnetic field due to the coil, using iron filings as in Exercise 28. (Disconnect the terminals of the storage battery when through, so as not to waste its energy.)

What form do you find the lines of magnetic force to take about a wire conveying a current?

V. Trace, by means of iron filings, the magnetic field due to a helical coil conveying an electric current. How does this compare with the field due to a long magnet? (See Exercise 28, II.)

Test the coil with a compass-needle, and determine which end attracts the north pole and which the south pole of the needle. If a soft iron rod were placed within the coil, in which direction would it be magnetized? Could the position of its poles be determined beforehand by the rule found in II, 6? How?

VI. Trace, in the same way, the field due to a flat coil in a plane parallel to that of the coil.

33. LAWS OF ELECTRO-MAGNETIC ACTION.

I. Take an upright wooden circle about 30 cm. in diameter, having a piece of insulated copper wire wound once around it with two free ends of about equal length twisted together so that the effect of an electric current in one will be neutralized by that of an equal and opposite current in the other. Place a compass-needle at the center of the coil, and set the coil so that its plane is parallel to the magnetic meridian.

Connect this rude galvanometer with some source furnishing a constant electric current, as a storage battery. Read the angle of deflection of the compass-needle. Reverse the direction of the current and read the angle again. Average the two results.

In what direction is the force tending to deflect the needle? (See Exercise 32.) To what function of the angle of deflection is this force proportional? (See Exercise 27, Proposition.)

II. Repeat I with a coil of the same diameter, but having twice the length of wire as in I, *i. e.*, having twice as many turns of wire.

III. Take another wire and wind it once around a wooden circle concentric with and of half the diameter of that used in I and II. Connect these two coils so that the same current will flow through them in opposite directions. Increase the number of turns of the larger coil until the effect of the smaller coil on the compass-needle is neutralized. How many turns of wire were necessary to do this? How does the length of wire in the larger coil compare with that in the smaller? How many times did the length of the wire have to be increased in order to neutralize the effect due to the decrease in the diameter of the coil?

IV. Set up three such rude galvanometers having coils of the same diameter and length, placing them as far apart as the table will allow, and connect them so that the whole current passes through one coil and half of the current through each of the other coils. Read the angle of deflection of each compass-needle. Reverse the direction of the current and average the east and west deflections of each galvanometer.

V. Answer the following questions, showing in each case the numerical process by which you arrived at your conclusion:—

1. How does the force at the center of a circular coil carry-

ing an electric current, vary with the length of wire in the coil, according to the results of I and II, assuming that it varies with some integral power (direct or inverse) of the length?

2. How with the diameter or radius of the coil, according to the results of III?

3. How with the current, according to the results of IV?

Assuming that the force F on a unit magnetic pole at the center of a circular coil depends only on the length, $L = 2\pi RN$, of wire in the coil, its radius, R, and the current, C, express this force in terms of these three quantities and a constant, K.

34. TESTING AN AMMETER.

I. Connect a rude tangent galvanometer, similar to those used in Exercise 33, in series with a storage cell and an ammeter. (See direction for setting up an ammeter in Exercise 35.) Place the instruments as far apart as the table will allow, and read the deflection of each. (Tap the ammeter as well as the galvanometer and be sure that their needles are free when they come to rest.)

Interchange the battery connections so as to reverse the current through both instruments, and read them again. Take the average of the readings before and after reversing the current. What source of error is eliminated in this way?

II. Reverse the direction of the current through the ammeter and repeat I. Take the mean of the average readings found in I and II. How is the mutual action of the two instruments eliminated in this way?

III. Repeat I and II with about 50 cm. of No. 25 German silver wire included in the circuit. What is the effect of this wire on the readings of the ammeter and the galvanometer?

IV. In Exercise 33 an equation was found connecting the

force, F, on a unit magnetic pole at the center of a coil conveying a current with the intensity of the current, C, the radius of the coil, R, the length of the wire in the coil, $L=2\pi RN$, and a constant K. The C. G. S. unit of current in the electro-magnetic system of units is the current that will exert a force of one dyne on a unit magnetic pole at the center of an arc 1 cm. long, of 1 cm. radius. If C, in the equation found in Exercise 33, was measured in terms of this unit, F in dynes, and R and L in cm., what will be the value of K? (Find by making F equal to 1 dyne, R equal to 1 cm., L equal to 1 cm., etc.) Having rid the equation of the constant K, find the value of C in terms of the other quantities, F, R, and L.

If H is the horizontal component of the earth's magnetic field and θ the angle of deflection of the needle, we have $F=H\ tan\theta$. (Ask for the proof of this equation, if you can not prove it yourself.) Substitute this value of F in the equation found above and thus obtain an expression for the current through a tangent galvanometer, in C. G. S. units, in terms of four measurable quantities, viz., the radius of the coil, R, the length of wire in the coil, $L=2\pi RN$, the horizontal component of the earth's field, H, and the tangent of the angle of deflection, θ. (Ask for the value of H.)

Measure the radius of the galvanometer coil and its length. Calculate, by means of the equation just found, the current in C. G. S. units through the galvanometer circuit in I and II. Do the same for the current in III. How do the results compare with the readings of the ammeter?

The ammeter is designed to read the current directly in "amperes,"—the unit of current in practical use. What, from your result, do you find to be the ratio between the C. G. S. unit of current and the ampere?

V. Alter the current, by introducing more or less German

silver wire into the circuit, and test the accuracy of the ammeter scale in various parts, as far as time will permit.

35. ELECTRICAL RESISTANCE.

Directions for Using the Ammeters.—In setting up an ammeter turn it so that the plane of the coil contains the magnetic meridian, and level it so that the needle swings freely. (The latter condition can be tested by deflecting the needle with a knife blade or steel key and observing its motion.) If there are two ammeters in use on the same table, they should be set at least 100 cm. apart. Any wire carrying a current in the immediate vicinity of an ammeter should be laid near and parallel, if possible, to another wire carrying an equal current in the opposite direction, so as to eliminate its effect on the needle.

In using an ammeter, or any other kind of galvanometer, always read the scale at both ends of the pointer, reverse the current, read at both ends again, and average the four readings to find the true reading. In this way all errors due to eccentricity of the circle with respect to the needle, to imperfect orientation of the coil, and to lack of symmetry in the construction of the needle, are completely eliminated. The instrument should also be jarred gently as the needle comes to rest.

I. (*a*) Connect an ammeter directly with the storage battery terminals and read the current.

(*b*) Introduce 50 cm. of No. 25 German silver wire into the circuit in series with the ammeter. (Use a specially constructed rheostat, with stretched wires of various sizes and a movable connection.) Read the current. How was its value altered, if any, by introducing this wire into the circuit?

(*c*) Repeat with 100 cm. of No. 25 German silver wire, at

the same time introducing into the circuit a wire equal in size and length to the wires leading to the battery. (Ask for directions.) What is the effect on the current of doubling the length of the wire in the circuit?

If we consider that the wire offers a certain kind of *resistance* to an electric current, and assume that the resistance varies as some integral power of its length, what do the results of (*b*) and (*c*) show this power to be? Is it direct, or inverse?

II. (*a*) Repeat I (*c*) with two No. 25 German silver wires, each 100 cm. long, connected in "parallel," instead of the single wire. What is the effect upon the current of paralleling the resistance wire with another wire of the same material and of equal diameter and length? [Compare the results of I (*c*) and II (*a*).]

(*b*) Remove the extra wire inserted in the circuit in I (*c*), and adjust the length of the two wires, if necessary, so that the current through the ammeter is the same as in I (*b*). How does the resistance of the two wires in parallel, after this adjustment, compare with the resistance of the single wire in I (*b*)? How do their lengths compare? What do you find to be the ratio of the resistance of a single wire to that of two wires of the same material, length, and diameter connected in parallel?

III. (*a*) Connect a No. 25 German silver wire 20 cm. long in series with the ammeter and read the current.

(*b*) Replace the No. 25 German silver wire by a No. 20 German silver wire of the same length, and measure the current again. What do you find to be the effect of increasing the cross-section of a wire upon the current? [Compare III (*a*) and III (*b*).]

(*c*) Adjust the length of the No. 20 German silver wire so that the current through the ammeter is the same as in III (*a*). How does the length of the No. 20 wire compare

with that of a No. 25 wire having the same electrical resistance? [See III (*a*).]

(*d*) With a screw gauge, or vernier calipers, measure the diameter of the No. 25 and also of the No. 20 wire. What is the ratio of the diameters of the two wires? What is the ratio of the resistance of a No. 25 wire to that of the same length of No. 20 wire, as deduced from the results of III (*a*) and III (*c*)? Assuming that the electrical resistance varies as some integral power of the diameter of a wire, what do you find the power in question to be? Is it direct, or inverse? How must the resistance vary, then, with the cross-section of the wire? How do the results of II (*b*) confirm your answer to this last question?

IV. (*a*) Introduce 50 cm. of No. 25 brass wire into the circuit, instead of the German silver wire, and measure the current. Do you find the resistance of brass wire to be the same as that of German silver wire? [Compare I (*b*) and IV (*a*).]

(*b*) Replace the brass wire by the No. 20 German silver wire and adjust its length so that the current through the ammeter is the same as in IV (*a*).

Having found a certain length of No. 20 German silver wire equal in resistance to 50 cm. of No. 25 brass wire, and knowing the diameters of these wires, calculate the relative resistance of brass and German silver wires of the same diameter and length.

V. (*a*) Connect a coil of fine insulated copper wire wound on a strip of wood in series with the ammeter and storage battery. Place the coil in a vessel of ice-water and read the current through the ammeter.

(*b*) Place the coil for a few minutes in a kettle of boiling water. Read the current again. What effect did the heating of the coil have upon the current? Did the heating of the copper increase or decrease its electrical resistance?

VI. (*a*) Replace the coil of copper wire by two plates of sheet copper held together by rubber bands and separated by strips of wood, or ebonite. (The plates should be washed thoroughly at the sink before being used.) Place the plates in a vessel of water fresh from the faucet and read the current through the ammeter, if there is any.

(*b*) Dip the same plates into water containing copper sulphate in solution and read the current again. Do you find the addition of copper sulphate to have any effect on the electrical resistance of the water? Was the electrical resistance increased or decreased?

VII. Repeat IV with iron wire instead of brass.

VIII. Repeat IV with fine copper instead of brass.

36. ELECTROMOTIVE FORCE.

I. (*a*) Connect a low-resistance galvanometer (an ammeter) directly to a Daniell cell and note the reading. Introduce another Daniell cell into the circuit in series with the first cell, connecting the copper plate of one cell to the zinc plate of the other, so that the currents due to both flow in the same direction through the ammeter. What change did the second cell produce in the reading of the ammeter, if any?

(*b*) Repeat the whole of (*a*) with a high-resistance galvanometer, constructed so that the effect on the deflection due to diminishing the current is offset by having a great length of wire in the coil. How did the change in the reading produced by introducing an additional cell into the circuit compare with that produced by the additional cell when an ammeter was used? Should a galvanometer of high or low resistance be used to show the effect of connecting two battery cells in series?

The effect of connecting two cells in series is to double the

electromotive force tending to produce an electric current in the circuit. What sort of a galvanometer (high or low resistance) do your results indicate should be used to measure the electromotive force due to any source of electric currents, or between two points of a circuit carrying a current? What is the objection to using a high-resistance galvanometer to measure the current flowing through a circuit? Would the current be the same after introducing such a galvanometer into the circuit as before?

The practical unit of electromotive force is called a "volt," and a high-resistance galvanometer graduated to give the electromotive force between its terminals in volts is called a "voltmeter." The instruments of this class used in (*b*) were designed for use as voltmeters and will be designated as such hereafter.

II. With a voltmeter measure the electromotive force of the following cells and combinations of cells, and answer the questions asked. (The directions for using an ammeter, see Exercise 35, apply also to a voltmeter.)

1. A Daniell cell.
2. Two Daniell cells in series, connected copper to zinc.
3. Two Daniell cells in series, connected copper to copper.
4. Two Daniell cells in parallel.

Are the electromotive forces of the individual Daniell cells equal? (Compare 1, 2, and 3.) How does the electromotive force of two Daniell cells in parallel compare with that of a single cell? With that of two cells in series? (Compare 1, 2, and 4.)

5. A Leclanché cell. (Zinc and carbon plates in a solution of sal ammoniac,—ammonium chloride.)

6. A Leclanché and a Daniell cell in series, connected carbon to zinc and copper to zinc.

7. The same cells in series, connected carbon to copper and zinc to zinc.

Is the electromotive force of a battery cell altered in any way when it is connected to another cell of different construction? (Compare 1, 5, 6, and 7.)

8. A Grenet cell. (Zinc and carbon in a solution of potassium bichromate and sulphuric acid.)

Remember to lift the zinc plate out of the bichromate solution as soon as you have completed your observations, for if left in, it will soon disappear under action of the acid.

9. A storage cell, using the terminals over the table.

10. A Bunsen cell. (Zinc in a sulphuric acid solution and carbon in a bichromate solution. In the original Bunsen cell the carbon was in concentrated nitric acid.)

III. Measure the electromotive force of a Daniell cell, and of a Leclanché cell, after being short-circuited for fifteen or twenty minutes. Was the electromotive force of the Daniell cell the same as that found in II? Was that of the Leclanché the same? If not, why? Which cell do you conclude is unsuitable for use where a constant current is required, as in telegraphing? Give a reason, if you can, why the other cell would be unsuitable for use where the circuit would only be closed for a moment at a time and at long intervals, as on a bell circuit.

IV. Measure the electromotive force of a cell composed of copper and zinc plates in dilute sulphuric acid; of the same plates in a bichromate solution; of carbon and zinc plates in dilute sulphuric acid; of the same plates in a bichromate solution. Do you find the electromotive force of a cell to depend on the material composing the two plates alone, on the electrolyte alone, or on both? Wash the plates thoroughly and sponge up carefully any acid that may have been dropped on the table.

37. OHM'S LAW.

I. (*a*) Connect a single Daniell cell in series with a rheostat and an ammeter. Take out enough plugs from the rheostat to introduce a resistance of 5 ohms* into the circuit. Read the ammeter carefully, reversing as usual. (Do not be surprised if the current is small.)

(*b*) Introduce another Daniell cell into the circuit in series with the first cell. Read the ammeter again.

How does the electromotive force in (*b*) compare with that in (*a*)? (See Exercise 36, II.) How does the current through the ammeter? What relation do you find to exist between the electromotive force and the current when the resistance is constant?

II. (*a*) With the connections as in I (*b*) take out enough plugs from the rheostat to increase the introduced resistance to 7 ohms. Read the ammeter.

(*b*) Repeat II (*a*) with all the rheostat plugs out. (Resistance = 10 ohms.)

How do the currents through the ammeter in I (*b*), II (*a*), and II (*b*), compare? How do the resistances of the circuits compare, neglecting the comparatively small resistance of the battery cells? What relation do you find to exist between the resistance and the current when the electromotive force is constant?

What, from the results of I and II, is the relation between the current in a circuit (or part of a circuit), the electromotive force acting through the circuit (or between its terminals, if it is not a complete circuit), and the resistance of the circuit (or part of a circuit)? This relation, when written correctly in the form of an equation (assuming the units of current, elec-

* The ohm is equal to the resistance at 0° C. of a column of mercury 106.3 cm. long and 1 sq. mm. in cross section.

tromotive force, and resistance to be so related that the constant factor becomes unity), is called *Ohm's law*.

III. Connect an ammeter and a voltmeter in parallel to the terminals of two Daniell cells connected in series, introducing a rheostat into the ammeter circuit.

Introduce, by means of the rheostat, resistances of 1, 2, 3, 4, 5, 6, 8, and 10 ohms into the ammeter circuit, reading in each case the ammeter and the voltmeter.

Tabulate your results, placing the resistance (in ohms) in the external circuit in one column, the corresponding current (in amperes) in another column, the electromotive force (in volts) in a third column, and in a fourth column the product of the resistance into the corresponding current. According to Ohm's law (see II), what should be the relation between the quantities in the third and fourth columns? Do you find this relation to hold true in every case?

IV. (*a*) If you have not the results of Exercise 36, measure with a voltmeter the electromotive force of a single Daniell cell; of two Daniell cells in parallel; of two Daniell cells in series.

(*b*) Connect the single Daniell cell directly to an ammeter and measure the current. Repeat with the two cells in parallel, and in series.

(*c*) From the results of IV, (*a*) and (*b*), calculate, by means of Ohm's law, the internal resistance of a single Daniell cell; of two Daniell cells in parallel; of two in series.

V. Find, as in IV, the internal resistances of a Bunsen cell and of a "dry battery" cell; also the resistance of one of the storage battery circuits. Why can not the resistance of a Leclanché, or other "single fluid" cell, be found in this way?

38. DIVIDED CIRCUITS.

I. (*a*) Join two rheostats in parallel and connect them in series with a storage cell and an ammeter. Cut out the resistances in the rheostats, leaving but one ohm in one branch of the circuit, and two ohms in the other. Read the current through the ammeter.

(*b*) Place the ammeter in the branch circuit of one ohm's resistance, and measure the current in this branch.

(*c*) Measure in the same way the current in the branch circuit of two ohms' resistance.

(*d*) Answer the following questions:—

1. How does the current in the main circuit compare with the sum of the currents in the two branch circuits?

2. Does the greater current flow through the circuit of greater or less resistance?

3. The currents in a divided circuit are proportional to an integral power of the resistances of the branches. What do your results indicate this power to be? Is it direct, or inverse?

II. Repeat I with a resistance of two ohms in one of the divided circuits and of five ohms in the other, and answer again the questions in I (*d*).

III. Connect the two rheostats with a third so as to form three parallel circuits of one, two, and three ohms' resistance, respectively. Measure with an ammeter, as was done in I and II, the current in the main circuit and in each of the branch circuits. Measure with a voltmeter the electromotive force between the two junctions of the parallel circuits.

Is the relation found in I and II between the currents in the branch circuits and the resistances of the circuits confirmed by the results of III?

IV. Calculate from the readings of the ammeter and voltmeter, by means of Ohm's law, the combined resistance of the three circuits in III when joined in parallel. Do you find this

to be greater or less than the resistances of the branches taken separately?

The reciprocal of the resistance of a conductor of electricity is called its *conductivity*. Calculate the conductivity of each of the parallel circuits in III separately, and also the conductivity of the three in parallel. Is the sum of the separate conductivities of the branches of the divided circuit equal to, greater, or less than the actual conductivity of the circuit?

V. Show algebraically that, if Ohm's law is true, the relations found in I and IV must necessarily follow.

39. ARRANGEMENT OF BATTERY CELLS AND FALL OF POTENTIAL ALONG A CONDUCTOR.

I. Connect three Daniell cells in series with each other (zinc to copper) and in series with an ammeter and a rheostat. Measure the current through the ammeter (1) when there is no resistance in the circuit external to the cells; (2) when a resistance of three ohms is introduced; (3) when five ohms are introduced; (4) when ten ohms are introduced.

II. Repeat I with the three cells connected in parallel (coppers together and zincs together).

Which arrangement of cells gave the greatest current when there was no external resistance in the circuit? Which when a resistance of ten ohms was introduced? Explain why in each case. In general, how should a number of battery cells be connected in order to obtain as large a current as possible (1) when the resistance in the external circuit is very small; (2) when it is comparatively large?

III. Connect three Daniell cells in series with each other and an external resistance of 10 ohms. Beginning at one end

of the rheostat, measure with a voltmeter the electromotive force between two points in the circuit separated by a resistance of one ohm, and repeat this measurement for each resistance in the rheostat. Is the electromotive force between two points of the circuit separated by a resistance of one ohm the same in all parts of the circuit?

IV. With the cells and rheostat (or rheostats) connected as in III, measure with the voltmeter the electromotive forces between one of the terminal plates and points on the circuit separated from this plate by resistance of 1, 2, 3, 5, 8, and 10 ohms respectively. Do you find the increase in electromotive force along the conductor to be proportional to the resistance, or not? What is the relation between the electromotive force and the difference of potential? Is the fall of potential then proportional to the resistance, or not?

V. Repeat IV, starting from the other terminal plate of the battery.

VI. Apply Ohm's law to the case of battery cells connected in series and in parallel, and show which would be the most advantageous arrangement when the external resistance is large, and which when it is comparatively small. Are the conclusions arrived at in II from experimental data consistent with those deduced thus from theoretical considerations?

Show that, if Ohm's law is true, the fall of potential along a conductor must follow the law found in IV.

40. COMPARISON OF RESISTANCES,—WHEATSTONE'S BRIDGE.

I. Connect a Leclanché cell to the bridge-wire of a Wheatstone's bridge, and connect a sensitive galvanoscope, by one terminal, to the sliding contact. (As the galvanoscope is

simply used to show the presence or absence of an electric current, the motion of its needle is restricted to a few degrees.) Connect also two rheostats in series with each other and in parallel with the bridge-wire, and join the free terminal of the galvanoscope to the junction of the two rheostats. A circuit of six branches is thus formed, with the galvanoscope in one branch, the battery cell in another, the rheostats in two branches, and two branches formed by portions of the bridge-wire.

With a resistance of five ohms in each rheostat set the sliding contact so that there is no current through the galvanoscope.

Measure the lengths of the two portions into which the bridge-wire is divided. What is the ratio of these two lengths? How does this ratio compare with the ratio between the two resistances in the rheostats?

II. Repeat I, with resistances of 5 and 10 ohms, respectively, in the rheostats; with resistances of 7 and 10 ohms. What proportion do you find can always be formed between the resistances in the rheostat branches and the two lengths into which the bridge-wire is divided when there is no current through the galvanoscope?

III. What must be the difference of potential between the two points where the galvanoscope is connected when there is no current indicated? Show by applying Ohm's law to the four branches formed by the two parts of the bridge-wire and the two resistances, that, when this is the case, the proportion found in II must hold true.

IV. Replace one of the rheostats by 100 cm. of No. 25 German silver wire. Adjust the sliding contact so that there is no current through the galvanoscope, and measure the lengths into which the bridge-wire is divided. Using the rheostat resistance as a standard, calculate, by means of the

proportion found in II, the resistance of 100 cm. of No. 25 German silver wire.

V. Repeat IV with various coils of wire on the table, instead of the German silver wire, and find the respective resistances of these coils.

VI. Repeat IV with a coil of fine copper wire immersed in cold water, and then in hot water, taking the temperature of the water in each case. From your results calculate: (1) The resistance of the coil at each temperature; (2) the change in resistance per degree rise in temperature; (3) the resistance at 0°; (4) the change in resistance per degree rise in temperature of each ohm at 0°: The last result will be the *temperature coefficient* of the electrical resistance of copper.

41. EFFECT OF AN ELECTRIC CURRENT. HEATING.

I. Weigh two small copper vessels and place in each of them 100 gm. of ice-water. To a cork, to fit one of the vessels, is attached a one-ohm coil of No. 25 insulated German silver wire. Arrange this coil in series with an ammeter and connect them "in shunt" to two points on a German silver wire in the power circuit. One of the connections should be a sliding terminal, by means of which the current may be adjusted to any desired value. Adjust this so that the ammeter reads about four amperes, and, after carefully taking the temperature of the water in both vessels, place the coil in one of them, inserting the cork. Record the time and close the circuit. Read and record the temperature of the water every two minutes, by means of a thermometer inserted through the cork, keeping the current constant at four amperes. (Stir the water by shaking the vessel gently whenever its temperature is taken.) When the temperature of the water in the vessel

containing the coil has nearly reached the temperature of the room, break the circuit and record the time. Then remove the coil from the vessel and again take the temperature of the water carefully in both vessels.

II. Reduce the current to about one-half of its value in I, and repeat I with the reduced current.

III. Repeat, using a coil of one-half ohm's resistance, and the same intensity of current as in I.

IV. Calculate the heating effect of the current in each of the three cases, I, II, and III (in degrees per minute).

The heating of a conductor by an electric current is proportional to an integral power of the current. What is this power as indicated by the results of I and II?

It is also proportional to some power of the resistance of the conductor. What is this power as indicated by the results of I and III?

V. What becomes of the energy expended in maintaining an electric current through a conductor?

The energy expended per second in maintaining an electric current through a conductor is equal, when the proper units are used, to the product of a certain power (see IV) of the current into a certain power (see IV) of the resistance of the conductor. If the current is measured in amperes and the resistance in ohms, this product will give the energy expended per second in terms of a unit called the "watt." Calculate in watts the energy per second (*i. e.*, the *power*) expended in maintaining the current through the German silver coil in I. (Use the average value of the current during the period of observation.)

Calculate the heat imparted to the coil per second on the assumption that it is all given up to the water and the vessel, using the same value for the specific heat of the vessel as in Exercise 8, III. Express the result in units of energy (or

work) per second. [1 calorie per second=41,900,000 ergs (dyne-cm.) per second.]

Having found the power (energy per second) expended in maintaining the current, and the heat imparted to the coil in a second, calculate the value of a watt in ergs per second.

VI. Calculate, as in V, the value of a watt in ergs per second, using the results of II and also of III.

VII. Find an expression for the power necessary to maintain an electric current in terms of the electromotive force and the intensity of the current, by substituting for the resistance its value (as given by Ohm's law) in terms of the electromotive force and the intensity of the current.

42. EFFECT OF AN ELECTRIC CURRENT. ELECTROLYSIS.

I. Wash and dry the six plates of three simple copper voltameters and scour them with emery cloth. Weigh these plates carefully on a sensitive Jolly balance, recording the numbers on the plates in order to identify them later. Place the plates in the copper sulphate solution of the voltameters, two plates in each voltameter, separated so that the whole current will be obliged to flow through the solution between them. (If you do not understand it, ask to be shown the method of inserting the plates in the cells.) The voltameters are connected so that the whole current flows through one, and one-half the current through each of the other two. The plates should be arranged so that the current will enter each voltameter by one of the three heaviest plates, and leave by one of the three lightest. Draw a diagram to show the arrangement of the plates in the voltameters. Connect the

voltameters in series with an ammeter and the storage battery terminals, and determine with a compass the direction of the current. Indicate on your diagram the direction of the current. Let the current flow through the circuit for an hour without interruption, reading the ammeter and recording the value of the current every two minutes.

At the expiration of the hour, take the voltameter plates, wash, dry, and reweigh them. Record on your diagram the loss or gain in weight of each plate.

II. Answer the following questions:—

1. In the voltameters, which plates gained in mass and which lost, those by which the current entered, or those by which the current left the liquid? Was the copper carried with or against the current?

2. In each voltameter how did the gain in mass of one plate compare with the loss in mass of the other plate?

3. How did the gain and loss in mass of the plates in each of the voltameters through which only part of the current passed compare with that in the voltameter through which the whole current passed?

How did the mass of copper deposited vary with the intensity of the current, assuming that the rate of deposition is proportional to an integral power of the current? (See question 3.)

III. Find the average value of the current in I, and calculate from your results the mass of copper that would be deposited from a copper sulphate solution by a current of one ampere flowing for one second.

IV. Repeat I with a voltameter consisting of two zinc plates in a zinc sulphate solution, and find the mass of zinc that would be deposited from such a solution by a current of one ampere flowing for one second.

43. ELECTROMAGNETIC INDUCTION.

I. Connect a coil of wire to a very sensitive galvanometer. (Ask for instructions before doing so, and be careful not to disturb the galvanometer and accessory apparatus.) Hold this coil in the field of an electromagnet, perpendicular to the direction of the magnetic field. Then turn the coil through 90°, so that it becomes parallel to the direction of the field. Note the deflection of the galvanometer and the direction (whether clockwise or counter-clockwise as one looks in the direction of the force-lines) of the current induced in the coil by rotating it in the magnetic field.

II. Hold the coil in the same position as in I, and press it flat instead of rotating it. Note again the deflection of the galvanometer and the direction of the induced current.

III. Hold the coil stationary in the same position as in I, and remove the electromagnet. Note again the deflection of the galvanometer and the direction of the induced current.

How did the currents induced in the coil in I, II, and III compare? If they are the same, explain this fact on the assumption that the current induced in the closed conductor, or coil, is due to the change in the number of force-lines passing through the coil. If the coil were viewed in the direction of the force-lines, in what direction do your results show the induced current to be when the number of force lines passing through the coil is diminished?

IV. Repeat I with the same coil, but with twice as much resistance in the circuit, the extra wire being connected in the circuit outside the coil. Compare the current induced with that induced in I. How did it vary with the resistance in the circuit? Which is the quantity that remained constant, the induced current or its electromotive force? Strictly, then, was the effect of rotating the coil to induce a current or an electromotive force in it?

V. (*a*) Remove the extra resistance, and rotate the coil from its final position in I through another 90°. Apply the rule deduced in III, for the direction of the induced current (electromotive force). Does it still hold true?

(*b*) Rotate the coil through 180° more. What is the effect of increasing the number of force-lines through the coil on the direction of the induced current (electromotive force)?

VI. Repeat V (*b*) with a coil having twice as many turns of wire. How do you find the induction to vary with the number of turns of wire in the coil? If you consider each turn as enclosing a certain number of force-lines, how then does the induction vary with the total change in the number of the force-lines threading through the coil?

VII. (*a*) Hold the coil stationary, as in III, and remove the core only of the electromagnet. If the galvanometer is deflected, read the deflection. Replace the core and read the deflection, if any, again. Explain the effect in each case.

(*b*) Remove the core very slowly and read the deflection of the galvanometer. Does this experiment indicate that the induced current (electromotive force) varies with the rate at which the change in the magnetic field is produced? How does the rate of change affect the induced electromotive force?

VIII. The general laws of electromagnetic induction may be stated thus: When the magnetic field is altered in any way with respect to an electric conductor, an electromotive force is induced in the conductor. This induced electromotive force is proportional to the rate of change in the magnetic field, and its direction is such as to produce a current that will oppose the change in the field.

Show how the results obtained in I—VII may be explained by means of this law.

44. EARTH-INDUCTOR.

I. (*a*) Set up a sensitive galvanometer and connect it with an earth-inductor, placing them as far apart as the table will allow. Place the earth-inductor so that the two stationary, upright supports are in an east and west line, and set the circle so that its axis of rotation is horizontal.

Turn the circle slowly into a horizontal position, let the galvanometer-needle come to rest, and then turn the circle suddenly through 180°, noting the effect on the galvanometer. Explain the cause of the current produced.

(*b*) Turn the circle in the same direction through another 180°, and compare the induced current with that in I (*a*). Was its direction the same? What would its direction have been if there had been no commutator?

(*c*) Rotate the coil continuously and uniformly, recording the number of turns per minute and the deflection of the galvanometer.

II. Set the coil so that its axis of rotation is approximately in the direction of the earth's magnetic field (at an angle of about 62° with the horizontal). Rotate it continuously as was done in I (*c*), recording again the number of turns per minute and the deflection of the galvanometer, if any. How does the current induced compare with that in I (*c*)? Explain the difference, if there is any.

III. Set the coil as in I, and rotate it continuously at a rate either one-half or twice as great as in I (*c*). What effect do you find a change in the rate of rotation to have upon the value of the induced current?

IV. Repeat I (*c*) with the axis of rotation vertical, rotating the coil as nearly as possible at the same rate. To what component of the earth's magnetic field is the induced current proportional in this case? To what component was it

proportional in I (*c*). How might the angle of dip be calculated from the observations made in this section and in I (c)? Using a table of natural tangents, calculate thus the angle of dip at Berkeley.

V. By varying the angle of inclination of the coil, find a position for which there will be no current induced when the coil is rotated. Read the angle of inclination, if the earth-inductor has a graduated circle. What is the relation between this angle and the angle of dip? How does the value of the angle of dip found in this way compare with that found in IV?

VI. Turn the base of the earth-inductor through 90° and rotate the coil continuously about a vertical axis, as in IV, at the same rate. How do you find the induced current to compare with that in IV? Explain the difference, if there is any.

VII. Answer the following questions and give reasons for your answers:—

1. Would there have been any current induced if the coil had been moved parallel to itself?

2. Would there have been any current induced if the coil had been moved parallel to itself with a strong magnet in its neighborhood?

3. What would be the effect on the induced current if a soft iron core were placed within the coil of the earth inductor.